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STATE OF CALIFORNIA

The Resources Agency

Department of Water Resources

BULLETIN No. 113-2

VEGETATIVE WATER USE

AUGUST 1967

RONALD REAGAN
Governor
State of California

WILLIAM R. GIANELLI
Director
Department of Water Resources

ERRATA SHEET

to

Bulletin No. 113-2, "Vegetative Water Use"

Please make the following corrections:

Page 24, Figure 5

Under, "TRANSECTS", the entry below A–"Central Valley" should read **(Plates 1 and 2)** and below B–"Coast to San Joaquin Valley" should read **(Figures 6 and 7)**

Page 28, Figure 7

The scale of the transect is approximately 1 inch equals 26 miles.

Page 38, Table 7, "Bakersfield Area"

The annual 1963 value under "Evapotranspiration" is **50.2.**

The annual 1963 value under "Pan Coefficients" is **0.81.**

The average annual value under "Pan Coefficients" is **0.80.**

Page 39, Table 7, "Salinas Valley, Vicinity of Soledad"

Place a **line** between "December" and "Annual" values.

Page 53, Table 12

Under "Assumptions" the entry "Harvest Data" should read **Harvest Date.**

Page 56, Figure 13

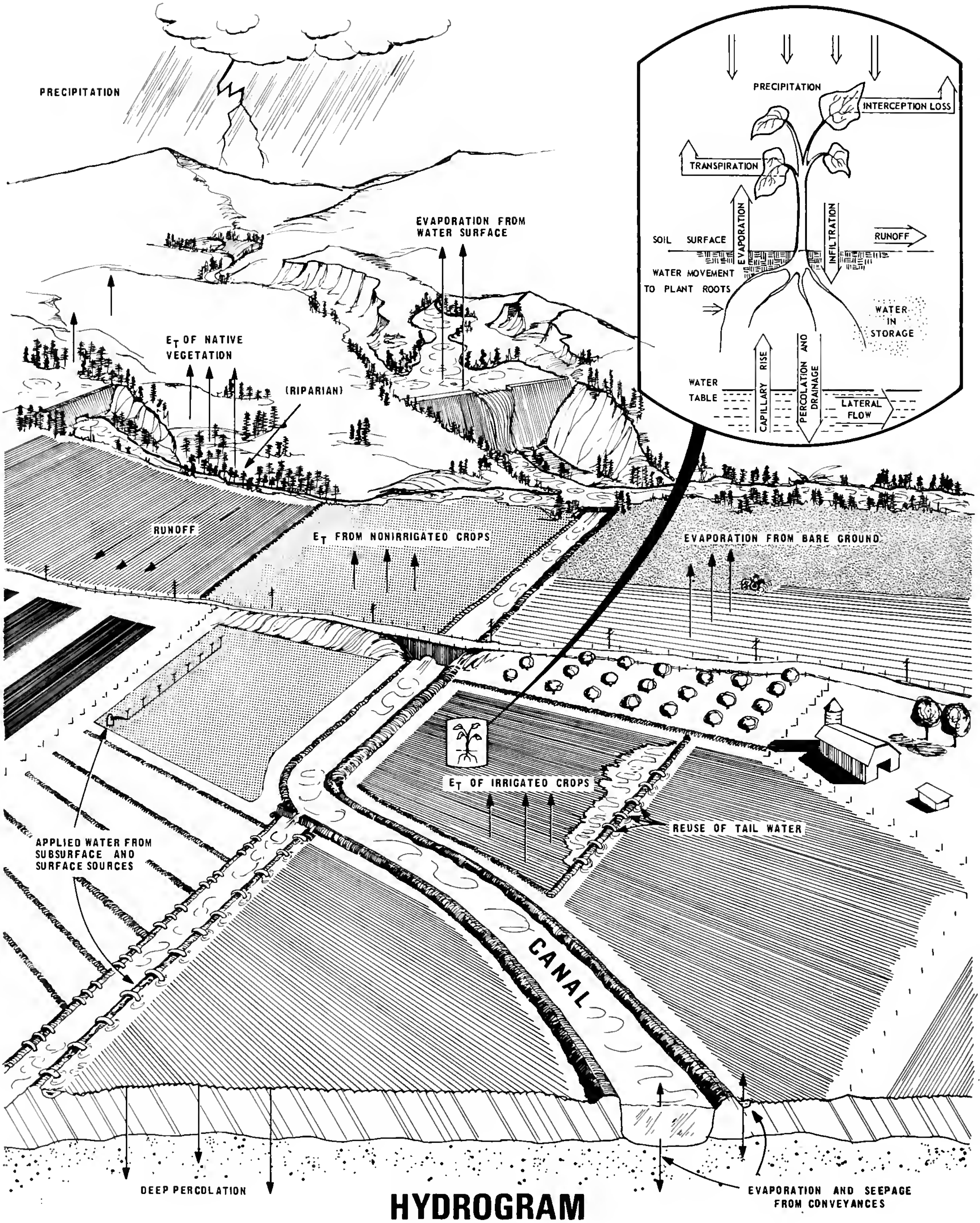
The line for the "2 x 2 Skiprow" cotton curves in the upper right block should be **dashed.**

Page 65, "Example of Basic Procedure"

All references to "San Joaquin Valley" should be preceded by the word **Southern.**

Back of Report, Plate 1

Under the month of October place a **rectangle** around the station "Vernalis No. 2 (4SE)".


PRECIPITATION
EVAPORATION FROM WATER SURFACE
E_T OF NATIVE VEGETATION
(RIPARIAN)
RUNOFF
E_T FROM NONIRRIGATED CROPS
EVAPORATION FROM BARE GROUND
E_T OF IRRIGATED CROPS
REUSE OF TAIL WATER
APPLIED WATER FROM SUBSURFACE AND SURFACE SOURCES
CANAL
DEEP PERCOLATION
EVAPORATION AND SEEPAGE FROM CONVEYANCES
PRECIPITATION
INTERCEPTION LOSS
TRANSPIRATION
EVAPORATION
INFILTRATION
SOIL SURFACE
RUNOFF
WATER MOVEMENT TO PLANT ROOTS
WATER IN STORAGE
CAPILLARY RISE
PERCOLATION AND DRAINAGE
WATER TABLE
LATERAL FLOW

HYDROGRAM

STATE OF CALIFORNIA

The Resources Agency

Department of Water Resources

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VEGETATIVE WATER USE

AUGUST 1967

RONALD REAGAN
Governor
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WILLIAM R. GIANELLI
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BULLETIN NO. 113 SERIES

This is the second report in the Bulletin No. 113 series. The reports are published by the Department of Water Resources for the use of all interested agencies and the general public. The first report is:

Bulletin No. 113, "Vegetative Water Use Studies, 1954-1960", August 1963.

FOREWORD

The vegetative water use studies upon which this report is based were initiated in July 1954 and broadened in 1959, pursuant to Senate Bill 434, 1959 Legislative Session. Specific authorization for conducting these studies is set forth in Section 226 (e) of the Water Code, which states that the Department may "conduct investigations of the rate of use of water for various purposes and considering various soil conditions". This report presents data and results which supplement and improve the findings reported in Bulletin No. 113, the first report in this series.

Included in this report are measured evapotranspiration rates of six important crops and measurements and estimates of soil, plant, and climatic factors, which correlate with or affect such rates. These data have been used to estimate total and monthly values of evapotranspiration, evapotranspiration of applied water, and evapotranspiration of precipitation for selected irrigated crops. Procedures have been developed for making such estimates for other irrigated crops and for estimating total and monthly evapotranspiration of precipitation for nonirrigated crops and native vegetation.

The resulting values will enable those concerned with planning and development of water resources and the operation of water projects to make more reliable estimates of water requirements and demands for project water.

William R. Gianelli

William R. Gianelli, Director
Department of Water Resources
The Resources Agency
State of California
June 26, 1967

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State of California
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Technical assistance provided by

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ACKNOWLEDGEMENTS

The assistance provided by public agencies in helping to establish and sustain a statewide vegetative water use program has been very valuable, and has permitted the Department of Water Resources to pursue a more extensive program of study than otherwise would have been possible. For the cooperation rendered by the following agencies, the Department is particularly grateful:

San Luis Obispo County Flood Control and Water Conservation District

Monterey County Flood Control and Water Conservation District

Correctional Training Facility (C.T.F.),Soledad

California Correctional Institution, Tehachapi (Cummings Valley)

In addition, the Department deeply appreciates the cooperation of the individuals and private organizations who provided the use of their property, equipment, and time for setting up and operating agroclimatic stations and soil moisture depletion plots. Without such assistance, much of the vegetative water use data would not have been collected. Unfortunately, the list of these many cooperators is too long to include here.

Special recognition is due Mr. W. O. Pruitt and others of the Department of Water Science and Engineering of the University of California at Davis for continuing counsel and technical advice given to the vegetative water use program.

ABSTRACT

This report, the second in the Bulletin 113 series, presents current data and results on vegetative water use which supplement and improve the findings of the first report. The data and results are based on studies conducted in central and northern California. / Included in the report are tables of measured pan evaporation, atmometer evaporation, and evapotranspiration data; recommended pan and atmometer evapotranspiration coefficients; recommended total evapotranspiration values and evapotranspiration of applied water values. The report also contains a discussion of the factors affecting evapotranspiration and the factors affecting estimates of irrigation requirements. / Activities carried out under the program are grouped into four main categories: 1) data collection, reduction, and analysis, 2) application of data to estimate monthly and annual evapotranspiration values, 3) separation of monthly evapotranspiration values into evapotranspiration of applied water and precipitation, and 4) estimation of irrigation requirements and net water use. / For irrigated crops, the basic procedure for estimating total and monthly evapotranspiration values is to correlate measurements of evapotranspiration for a specific crop with measurements of evaporative demand measured in a standardized pasture environment. The coefficients developed can then be used with evaporation data from pasture environments in any portion of similar evaporative demand zones to estimate evapotranspiration for the same or like crops. Separation of the estimated evapotranspiration values into evapotranspiration of applied water and precipitation is accomplished by making certain assumptions on effective root zone, available soil moisture capacity, and ground cover conditions and then using the assumptions along with precipitation and evapotranspiration data to maintain a budget or running account of soil moisture accretions and depletions. / In the case of nonirrigated crops and native vegetation, estimates of potential evapotranspiration, plant rooting depth, soil moisture holding capacity, growing season, and ground cover conditions are used with precipitation records representative of the study area to determine the amount of water temporarily stored in the soil and later utilized by the vegetation. This information is arranged in a manner that shows evapotranspiration of direct and stored precipitation for each month. / Comparisons of evapotranspiration of applied water values estimated from current studies with those presented in Bulletin No. 2 show that current values generally exceed the Bulletin No. 2 values. When the higher values are used to calculate 1960 and 2015 evapotranspiration of applied water quantities for six crops in three areas of the Central Valley, it is found that more recent values differ from estimates based on Bulletin No. 2 values by 1,077,000 acre-feet in 1960 and 1,622,000 acre-feet in 2015. These quantities represent a 15 and 17 percent increase, respectively.

CHAPTER I: INTRODUCTION AND CONCLUSIONS

The Vegetative Water Use Program was established in recognition of the need for more reliable information consistent with the more detailed water development planning required for implementation of the California Water Plan. Data needed for present water resource planning differ in many respects from the data needed in earlier studies. In studies undertaken for the preparation of Bulletin No. 2, "Water Utilization and Requirements of California, June 1955", estimates of water requirements were based on annual unit water use values developed empirically by using mean monthly temperature and percent of daylight hours, and modified by use of carryover moisture and precipitation occurring during the growing season. These unit values proved acceptable for the purpose of approximating present and future annual irrigation requirements for broad-scale planning.

However, as a result of increased emphasis on more detailed planning, it soon became apparent that more accurate water use information was needed for specific areas, and for monthly rather than annual time periods. Increasing emphasis is now being given to determining all component water uses and losses that relate to water requirements of all types of vegetation and to evapotranspiration of applied water of irrigated crops.

Program Objectives

The general objectives of the Vegetative Water Use Program are to develop procedures for (1) estimating monthly and annual unit values of water use and (2) estimating irrigation requirements and net water use. The first objective includes the determination of monthly and annual evapotranspiration rates of irrigated and nonirrigated crops and native vegetation throughout the State, and the separation of monthly evapotranspiration values into evapotranspiration of applied water and evapotranspiration of precipitation. The second objective includes the determination of irrigation efficiencies and the extent of irrecoverable water losses.

Comparison of Present and Historic Unit Water Use Values

New recommended unit water use values that vary considerably from values previously used, have been derived from data collected under this program. The extent of the variance of the values developed in Chapter IV of this report and mean seasonal values presented in Bulletin No. 2 for the Central Valley are shown in Table 1.

TABLE 1
COMPARISON OF GROWING SEASON EVAPOTRANSPIRATION
OF APPLIED WATER VALUES
CENTRAL VALLEY
(acre-feet per acre)

Crop	Current Values1/	Bulletin No. 2
Sacramento Valley Floor		
Pasture (improved)	3.2	2.5 - 2.7
Alfalfa	2.7	2.2 - 2.6
Orchard (plums)	2.2	1.4 - 1.7
Sugar Beets	2.2	1.3 - 1.6
Rice	4.1	4.1
San Joaquin Valley Floor		
Pasture (improved)	3.4	2.7 - 3.0
Alfalfa	3.0	2.7 - 3.0
Orchard (plums)	2.5	1.8 - 2.1
Cotton	2.4	1.4 - 1.7
Sugar Beets	2.3	1.6 - 1.9
Tulare Lake Basin Valley Floor		
Pasture (improved)	3.5	2.8 - 3.1
Alfalfa	3.3	2.8 - 3.1
Orchard (plums)	2.8	2.0 - 2.3
Cotton	2.5	1.9 - 2.3
Sugar Beets	2.5	1.6 - 2.0

1/ Refer to Chapter IV for a discussion of the development of these values and to Table 18, Chapter IV for the monthly values.

Although these higher growing season values are important in estimates of water requirements, of equal importance in such estimates are the monthly values developed under the current studies -- values which were not previously available.

Although the percentage differences for some individual crops appear to be quite substantial, a more realistic comparison of the overall effect of the currently recommended values is found in Table 2. When compared to the current results, the evapotranspiration of applied water determined by using Bulletin No. 2 values is underestimated by 15 percent and 17 percent respectively, for 1960 and 2015. This example demonstrates the importance of continually evaluating and, where necessary, modifying or supplementing historical unit water use values.

Program Activities

The various activities to accomplish the program objectives are carried out by the Department and by outside agencies under research contracts to the Department.

Department of Water Resources Activities

The full range of the Department's vegetative water use activities progresses from the collection of evaporation, evapotranspiration, and related data, to the application of such data to estimate total and net irrigation requirements. These activities may be logically grouped into the following four categories:

1. Data collection, reduction, and analysis.
2. Application of data to estimate monthly and annual evapotranspiration values.
3. Separation of monthly evapotranspiration values into evapotranspiration of applied water and evapotranspiration of precipitation.
4. Estimation of irrigation requirements and net water use.

Research Supported by Department of Water Resources

Because of its need for resolution of technical problems relating to soil-water-plant relationships, the Department has for many years supported vegetative water use research conducted by the University of California and the Agricultural Research Service of the U. S. Department of Agriculture. Current agreements with the two agencies provided funds for research to (1) determine the relative effects of certain climatic variables on evapotranspiration rates of irrigated crops and native vegetation and (2) develop equipment and techniques that can integrate the important variables and effectively measure or predict actual evapotranspiration.

Table 2
COMPARISON OF ESTIMATED
EVAPOTRANSPIRATION OF APPLIED WATER
IN THREE AREAS OF THE CENTRAL VALLEY
FOR 1960 AND 2015

Area 1/	Crops Used in Comparison	Year	1000 Acres 2/	Evapotranspiration of Applied Water (1000 ac-ft)		
				Current Studies 3/	Bull. No. 2	Greater than Bull. No. 2
Tulare Lake Basin Valley Floor	Pasture, Alfalfa (Hay), Sugar Beets, Orchard, Cotton	1960 2015	1,430 2,051	4,054 6,066	3,486 5,182	568 884
San Joaquin Basin Valley Floor	Pasture, Alfalfa (Hay), Sugar, Beets, Orchard Cotton	1960 2015	786 1,040	2,350 3,047	1,977 2,562	373 487
Portion of Sacramento Valley Floor	Pasture, Alfalfa (Hay), Sugar Beets, Orchard, Rice	1960 2015	509 668	1,646 2,022	1,510 1,771	136 251
TOTAL		1960 2015	2,725 4/ 3,759 5/	8,050 11,136	6,973 9,515	1,077 1,622

1/ Delta area and northern portion of Sacramento Valley floor not included in comparison.

2/ Acres from Table 1 (Areas 12, 13, 15, 49 and 60), reported in "Supplemental Information for DWR Exhibit No. 80, Coordinated State Water Project, Central Valley Operation Study, August 1966"

3/ Refer to Table 17, Chapter IV for an example of the procedure used in determining evapotranspiration of applied water, and to Table 18, Chapter IV for a list of evapotranspiration of applied water values used for the crops in this comparison.

4/ This acreage represents a little more than 61 percent of the total 4,437,000 acres irrigated in the three areas in 1960.

5/ This acreage represents a little more than 55 percent of the total 6,808,000 irrigated acres projected for the three areas in the year 2015.

In pursuing these goals, both research agencies are engaged in two main activities. One is the testing of predictive evapotranspiration formulas which can be applied throughout the State; the other is the development of equipment which can be used to measure evapotranspiration. Until fairly recently, most of the research work has been in the investigation of the variables that affect evapotranspiration and in testing the many empirical, semiempirical, and theoretical formulas in which these variables have been combined.

Scope of Report

This report, the second in the Bulletin 113 series presents the current results and concepts regarding vegetative water use. It updates, modifies and, where necessary, expands the content of the first report, "Vegetative Water Use Studies, 1954-1960", August 1963. The findings presented in this report are based on data collected in central and northern California primarily between 1959 and 1964.

This report refers to a number of physical phenomena which occur in the soil-plant-climate regime and their effect on the evapotranspiration process. Because an understanding of the basic concepts surrounding these phenomena is necessary to an understanding of the procedures used in developing recommended monthly evapotranspiration coefficients and values, a discussion has been included of the more important concepts. This discussion is presented in Chapter II.

In Chapters III and IV, the data collected under the program are summarized, analyzed, and then applied in various ways to estimate monthly and total evapotranspiration and evapotranspiration of applied water.

Chapter V ends the report with a discussion of the important factors that must be considered in using the evapotranspiration of applied water values, presented in Chapter IV, to estimate irrigation requirements, project demands, and net water use.

Technical terms used in this report are listed and defined in Appendix A, "Definition of Terms". The periods of record of all evaporation data collected under the program are presented in Appendix B, "Availability of Historic Monthly Evaporation Data.

Summary of Conclusions

1. Unit water use values developed during the current program of field measurements substantially exceed the values derived from empirical methods during the preparation of the California Water Plan and published in Bulletin No. 2. As an example, evapotranspiration of applied water during the growing season for six of the major crops grown in three large representative valley floor areas in the Central Valley was determined during the current investigation to be 1,077,000 acre-feet, or 15 percent greater than estimated in Bulletin No. 2 values for 1960, and 1,622,000 acre-feet, or 17 percent greater for 2015. The six crops considered were improved pasture, alfalfa, cotton, deciduous orchard, rice, and sugar beets. These crops represent about 60 percent of the lands irrigated in those areas in 1960 and about 55 percent of the projected irrigated lands in 2015.

2. An analysis of evaporation data collected at 22 different locations since 1959 (using U. S. Weather Bureau evaporation pans and Livingston black and white atmometers under standardized environmental conditions for grass and pasture) indicates that the major agricultural areas of central and northern California can be grouped into four zones, each possessing its own monthly evaporative demands. These zones, in order of increasing evaporative demand are: Central Coast, Central Coastal Valleys, Northeastern Mountain Valleys, and the Central Valley. Similarly, each zone also possesses its own potential evapotranspiration.

3. Because of the fragmentary nature of data available for some of the agroclimatic zones, the annual variability of all evaporative demand data, and the relative shortness of period of record, additional years of record will be required for each of the agroclimatic zones before reliable long-time mean values can be attained. Continuous records of mean monthly evaporative demand based upon pan and atmometer measurements are currently available for seven agroclimatic stations in the Central Valley for only the period 1960 to date. Representative monthly evaporative demand values for estimating evapotranspiration within the Central Valley for any given month

of any given year during the period of record can be obtained using the average of the monthly evaporative demand values from the pan or atmometer agroclimatic stations for the given year.

4. The recommended monthly and growing season evapotranspiration rates for grass and improved pasture, alfalfa, cotton, deciduous orchards, and sugar beets are tentative only and must be used with judgment. These values were determined using recommended evapotranspiration coefficients based on field measurements of evapotranspiration and evaporative demands made between 1959 and 1965 at three different locations within the Central Valley and presented in this report. Although the procedure recommended for estimating these values (based on the premise that evapotranspiration rates vary directly with the evaporative demand) is sound, the values reported herein are termed "tentative" because they are based upon records that are insufficient in length, in area covered, and in variety of cultural practices or plant species measured.

5. The tentative recommended monthly evapotranspiration coefficients developed for estimating evapotranspiration of crops in the Central Valley agroclimatic zone can be used to estimate evapotranspiration for the same crops in other agroclimatic zones and for other crops, by relating information on dates of planting, emergence, and harvest; development of ground cover percentage, and estimates of crop surface roughness to similar conditions of measured crops.

6. The recommended procedure for estimating evapotranspiration of nonirrigated crops and native vegetation (based on a budget-keeping technique that compiles evapotranspiration of direct and stored precipitation) can be used to estimate the evapotranspiration of an entire watershed and to determine differences of water use due to changing land uses.

Proposed Future Activities

The first of the general objectives of the Vegetative Water Use Program is to estimate monthly and annual unit values of water use. This includes the determination of monthly and annual evapotranspiration rates for irrigated and nonirrigated crops and native vegetation throughout the State, and the separation of monthly evapotranspiration values into evapotranspiration of applied water and evapotranspiration of precipitation. Procedures are presented in this report which would permit the accomplishment of this objective. However, because of the shortness of record, the

fragmentation of data, and the small number of crops considered, the measured values of evapotranspiration and evaporative demand and the pan and atmometer evapotranspiration coefficients calculated from the values for use in the actual determination of the monthly and growing season unit values of water use, permit only the development of short-term tentative recommended values.

In order to obtain more reliable monthly values for any given year and long-term mean monthly values of evaporative demand and evapotranspiration, the following program elements will be continued or initiated.

1. The collection and analyses of pan and atmometer data to determine long-term mean monthly evaporative demands at the established agroclimatic stations, at selected former stations, and at new locations, and to determine monthly and annual evaporative demand values for any given year within any zone.

2. Measurements of evapotranspiration rates using evapotranspiration tanks and neutron probes at the present locations and at other locations to include not only crops previously measured but additional crops, and measurements using portable field instruments based on the energy balance concept, in cooperation with the contract agencies.

3. Further analyses of pan and atmometer evaporation data and evapotranspiration rates to determine reliable long-term mean monthly pan and atmometer evapotranspiration coefficients for all important crops within the agricultural areas of the State.

4. The collection and analyses of information on typical irrigation and cultural practices for crops required for extending results from evapotranspiration plots to other areas.

The second of the general objectives of the program is the determination of irrigation efficiencies and net water use for a particular farm or small area. These determinations will be made for principal crops within major agricultural areas by measuring:

a) Applied water to the field.
b) Percolation of applied water beyond root zones.
c) Runoff of applied water from the fields.
d) Change in soil moisture storage during the growing and nongrowing seasons.

These vegetative water use data will facilitate the determination of monthly and annual irrigation requirements. They will help in the planning of water resources projects.

CHAPTER II. FACTORS AFFECTING EVAPOTRANSPIRATION

Fundamental research indicates that the various factors affecting evapotranspiration (ET) may be grouped into three broad categories:

1. Climatic Factors - These include such factors as solar radiation, wind, humidity, temperature, and precipitation. The collective effect of these factors is the evaporative demand affecting the crop.

2. Plant Factors - The more important factors are percentage of ground surface covered by transpiring vegetation, state of plant development, plant physiological controls, and surface roughness of the crop.

3. Soil Factors - Of greatest importance is the availability of soil moisture to the crop, including not only the available moisture content of the soil mass within the root zone, but the transmissibility rate of moisture through the soil to plant roots.

Climatic Factors

While it is a more complex process, evapotranspiration is, in many respects, analogous to evaporation from a free water surface. Evapotranspiration may be thought of, simply, as the sum of evaporation from the plant leaf and from the underlying soil surface. Although plant and soil factors under certain conditions can exert a considerable effect upon evapotranspiration, during times when optimum conditions for growth are realized, the factors of climate have by far the greatest influence on such rates. The most important single climatic factor is solar radiation. The other factors of wind, humidity, and temperature exert considerable influence on the amount of solar or net radiant energy which goes into the evaporation process. Precipitation and its resultant affect on surface and subsurface moisture conditions can also be a very important factor.

Fundamental Concept - The Energy Balance

Solar radiation is the primary source of energy used in evapotranspiration. Of the total radiation reaching the earth's surface, a portion is reflected into space. Net radiation, the difference between incoming and outgoing radiation, is utilized for evapotranspiration; for heating the air, soil and plant; and for photosynthesis by the plant. This distribution of energy, which varies under different conditions, is illustrated in Figure 1 for an irrigated crop at midday when a maximum amount of radiation is available.

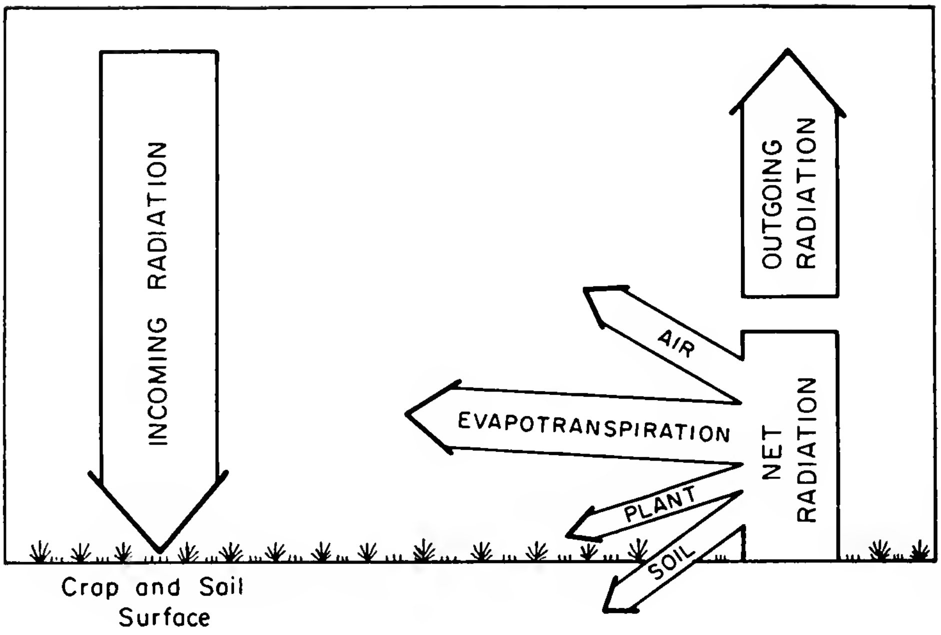


Figure I . ENERGY BALANCE AT MIDDAY WITHIN AN IRRIGATED CROP

As shown in the figure, the greatest amount of this net radiant energy is used directly in evapotranspiration and only a small portion goes to each of the other components.

The amount of heat stored in the soil may amount to ten percent of net radiation under some short-term conditions of clear weather. For periods of a week or longer, however, it normally is a much smaller portion of the total net solar energy and is generally neglected. The storage of heat in the crop and the energy used in photosynthesis by the plants is also considered to be small and is neglected in calculating evapotranspiration. The net radiation, therefore, is partitioned primarily between heating of the air and evapotranspiration.

Oasis Effect and Advective Energy

Under dryland conditions, or where there is limited moisture available for evapotranspiration, most of the energy is used in heating the air. This becomes important when considering an irrigated area bordered by a dryland environment. Such an irrigated area is considered to be an oasis. Research by many investigators has shown that the energy used to evaporate water from such irrigated fields is often greater than net radiation and sometimes exceeds even the total energy available from direct solar radiation. In such cases the direction of the arrow for air in Figure 1 is reversed, providing additional energy at the surface. In this situation, air warmed over the dryland and moved by the wind over the cropped area acts as a source of energy to the crop surface and results in an increased rate of evapotranspiration. The energy

given up in this manner is termed "advective energy", and the process by which it is transferred to irrigated fields is termed "advection".

When heat is added to the crop, as discussed above, the crop is advectively heated. However, over relatively narrow strips of land adjacent to the ocean or other large bodies of water, the reverse process, or advective cooling, may take place. Instead of receiving heat from the air, crops in such an environment give up heat to the cool air coming from over the water surfaces. As a result, the amount of energy going into evapotranspiration is reduced.

The dryland condition bordering or surrounding the oasis also can vary. Quite commonly, the dry areas adjacent to the irrigated crops in California support native grasses and dryland crops until soil moisture is depleted. In the early spring when soil moisture is available, both native grasses and dryland crops nearly cover the ground, and most of the net radiation goes into evapotranspiration. At this time, advection from the native vegetation or dry-farmed land area is minimal. However, as the soil moisture is exhausted, the vegetation ceases to transpire. By summer, considerable advective energy may move from dry areas over the irrigated fields, thus increasing evapotranspiration rates. Advection is of greatest significance during this period because the ratio of dry area to irrigated or moist area is the highest. Generally, the total advective energy per unit area from these dry farmed and native vegetation lands will be somewhat less than from fallow fields. This is because the vegetated area continues to lose moisture from the root zone by plant transpiration for some time after evaporation from the surface of fallow lands has decreased to a negligible amount.

The so-called "border effect" shown in Figure 2, on the following page, results when heated air comes in contact with the edge or border of an irrigated crop and moves into or through the crop. For large fields with reasonable planting densities, the importance of this effect in increasing water losses is relatively small because the warm air close to the surface is cooled rapidly and heat must be transferred from greater and greater heights. Small fields, on the other hand, may be strongly subject to the border effect and experience greater average water losses than a larger field.

Plant Factors

While evaporation from a shallow free water surface is limited only to the evaporative demand at the earth's surface, evapotranspiration may be controlled also

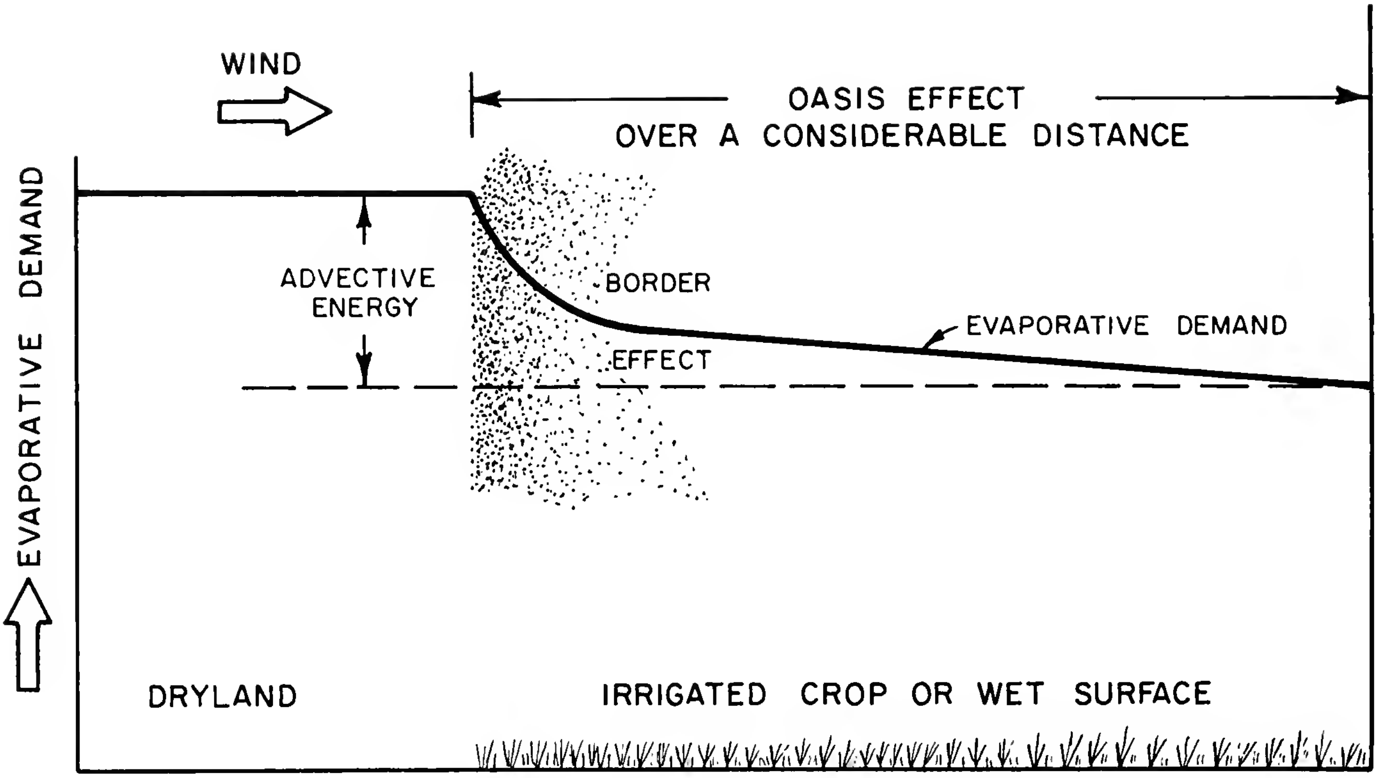


Figure 2. SUMMERTIME ADVECTION IN THE CENTRAL VALLEY

by the physiological and physical conditions of the transpiring vegetation.

Plant Physiology

The interrelationship of various physiological factors and their effects on evapotranspiration are complex. Plants are adapted to their environment through natural selection, and, therefore, have different characteristics which affect their rates of water use. For example, the leaves of some plants incur smaller water losses than others because they have waxey surfaces, sunken stomata, or hairy surfaces which reduce air movement at the leaf surface.

Young rapidly growing plants appear to have higher rates of evapotranspiration than mature plants under otherwise equal conditions. This is believed to be related to photosynthesis and the carbon dioxide-oxygen exchange rate. When the rate of photosynthesis is high, the stomata remain open to allow the exchange of carbon dioxide and oxygen to take place. This condition is favorable to a greater loss of water vapor from the plant. Periods of excessive evaporative demand may, however, cause these stomata to close for short periods of time to reduce the rate of evapotranspiration.

Percentage of Ground Cover

Evapotranspiration rates vary with the percentage of ground covered by transpiring crops. There is considerable variation in ground cover condition from crop to crop. Some crops have approximately the same ground cover percentage throughout the year. For example, pasture has nearly 100 percent cover throughout the season. In cold, high mountain valleys, however, where even grasses may go winter dormant, little transpiration occurs even though the percentage of ground cover remains constant. Citrus and olives provide a nearly constant cover throughout the year, but vary from orchard to orchard. Deciduous orchards, although providing a nearly constant cover when they are completely leafed out, furnish very little cover from the bare limbs during the late fall, winter, and early spring. Alfalfa, on the other hand, varies from approximately 10 percent to 100 percent ground cover between cuttings.

Annual row crops vary in percent ground cover from planting to harvest. Following emergence, the soil surface is usually dry and the energy and moisture transfer is largely from the crop foliage. Following an irrigation, the evaporating surface is approximately 100 percent for a short period of time until the ground surface again dries. As the crop grows both in height and width, the percent of ground cover rapidly increases. Due to other factors, such as the angle of the sun in relation to the earth's surface and orientation of the crop rows, the effective ground cover may be 100 percent long before the crop completely covers the ground. There is evidence that direct and advective energy may produce maximum evapotranspiration rates when actual ground cover is around 50 percent. Field measurements by the Department have verified this for cotton.

Crop Surface Roughness

Evapotranspiration is furthered by the turbulent mixing of the air above the crop. The roughness of the crop surface determines the degree of turbulence in the air moving over it. The air mixing serves two purposes: (1) it hastens the water vapor transfer away from the zone of high concentration near the evaporation surface, and (2) it increases the capacity for transfer of heat from the warm dry air above the saturated layer. Surface roughness can vary between stages of plant development for any given crop and between different crops at any given stage of development. The air above pasture, for example, is much smoother than the air above an orchard or vineyard. Row orientation with respect to wind direction can also change the effect of crop surface roughness on air turbulence.

Soil Factors

The primary means by which the soil can influence the rate of evapotranspiration is through the effect of various soil properties upon the storage capacity and availability of moisture at the soil surface or to the plant.

Evaporation from Soil Surfaces

The rate of movement of moisture through the soil to the surface is related primarily to soil texture and structure. Surface evaporation however, under usual irrigation practices, is not appreciably affected by the rate of moisture movement.

A soil with a very moist surface will lose about the same amount of moisture as a very shallow water body or an irrigated, improved pasture. Evaporation and/or evapotranspiration rates are nearly the same for all three. In each case, the evaporation rate is controlled almost entirely by the climate; that is, the evaporative demand. In cropped lands the plants act as a sort of wick, connecting the subsurface soil moisture to the atmosphere. With bare soils,the connection is broken as soon as the soil surface becomes dry through evaporation.

Availability of Soil Moisture to Plants

The availability of soil moisture to plants depends upon the amount that either can be or is stored within the soil, and upon various internal and external factors that limit the availability of such moisture. The following discussion includes some factors which are not soil factors but which do affect the moisture availability of the soil. The factors considered are (1) amount and intensity of precipitation, (2) the effective rooting depths of crops, (3) soil infiltration rates, and (4) available moisture holding capacity of the soil.

1. Amount and Intensity of Precipitation: Generally, under conditions of low precipitation, all the precipitation is intercepted by vegetation and evaporated or absorbed by the soil and subsequently transpired. As the total annual precipitation increases, evapotranspiration of this moisture, likewise, generally will increase, depending upon the distribution and intensity of the precipitation. The increase in moisture use continues until the monthly evaporative demand is met. Above this level additional precipitation will contribute either to return flow or deep percolation, or be retained in the soil until the upper limit of the soil moisture holding capacity is reached. Areas having high annual precipitation, in general, have less need for applied water than areas of low annual precipitation.

Not all precipitation, however, can be considered effective in reducing the applied water requirements. By definition, "Effective Precipitation" is that portion of precipitation that is utilized by the crop during the growing season. The amount of precipitation during the growing season and the amount of nongrowing season precipitation stored in the soil and used during the growing season, determines the relationship between evapotranspiration of applied water and the evapotranspiration of precipitation.

2. Effective Rooting Depth: The effective root depth of crops also is variable and may be limited either by actual soil depth, by depth of moisture penetration, or by plant rooting characteristics. Normally, a plant extracts most of its moisture from the upper layers of the soil and does not extend its roots any deeper than necessary to obtain an adequate supply. Many crops, such as pasture, cereal, and some truck normally are shallow rooted while alfalfa and orchards, for example, are deep rooted. A difference in rooting depth will change the amount of effective precipitation.

3. Infiltration Rates: The infiltration rate of soils is influenced by many factors. A discussion of these is beyond the scope of this report, other than to state that any time the intensity of rainfall exceeds the infiltration rate, surface runoff occurs and precipitation, which under different circumstances might have been effective, is lost.

4. Available Moisture Holding Capacity: The quantity of soil moisture available to plants is normally considered to be the amount of moisture held by the soil between field capacity and the permanent wilting point.

Neither of these points are precisely fixed because of the dynamic nature of soil water movement and plant physiological processes. Fine-textured soils generally have a greater available soil moisture holding capacity than coarse textured soils. For the "average" soil, an available moisture holding capacity of 1-1/2 inches per foot of depth is recommended.

Various concepts have been advanced regarding the effect of moisture availability on evapotranspiration rates of plants. According to one concept, the evapotranspiration rate decreases as available moisture in the soil decreases from field capacity to the permanent wilting point. Another concept is that, as long as available moisture exists within the root zone, the evapotranspiration rate will be unaffected.

Field observations by the Department relating soil moisture depletion from deep permeable soils to evapotranspiration, support the position that evapotranspiration rates are not affected over a wide range of soil moisture availability. However, there are indications that crop yields are sometimes materially affected before evapotranspiration rates decrease.

Concluding Remarks

While the numerous factors affecting evapotranspiration may at first appear to be so complex that realistic estimates of crop water use are beyond our present power to predict, this is not the case. Numerous factors do exist, but they are physical processes and subject to physical laws. Through an understanding of these physical processes, we gain the insight necessary to make reasonable estimates of water use by crops.

CHAPTER III - FIELD STUDIES

The main emphasis of the Department's field studies has been the correlation of measured evapotranspiration rates of various major agricultural crops with evaporative demand measurements under different climatic-geographic conditions.

Two separate, but complementary, studies exist to accomplish this goal:

1. Evaporative Demand Studies.
2. Evapotranspiration-Correlation Studies.

Evaporative Demand Studies

The objective of these studies is to define zones of similar evaporative demand within the major agricultural areas of the State. These zones provide the basis for developing the recommended evapotranspiration to evaporation coefficients used in estimating evapotranspiration for the principal crops of the State. The approach used in defining the zones is described in detail in the first report in this series Bulletin No. 113, "Vegetative Water Use Studies, 1954-1960", April 1964. Briefly, it consists of making direct measurements of evaporation rates of water from the following two types of evaporimeters:

1. U. S. Weather Bureau "Class A" evaporation pan.
2. Livingston black and white spherical atmometers.

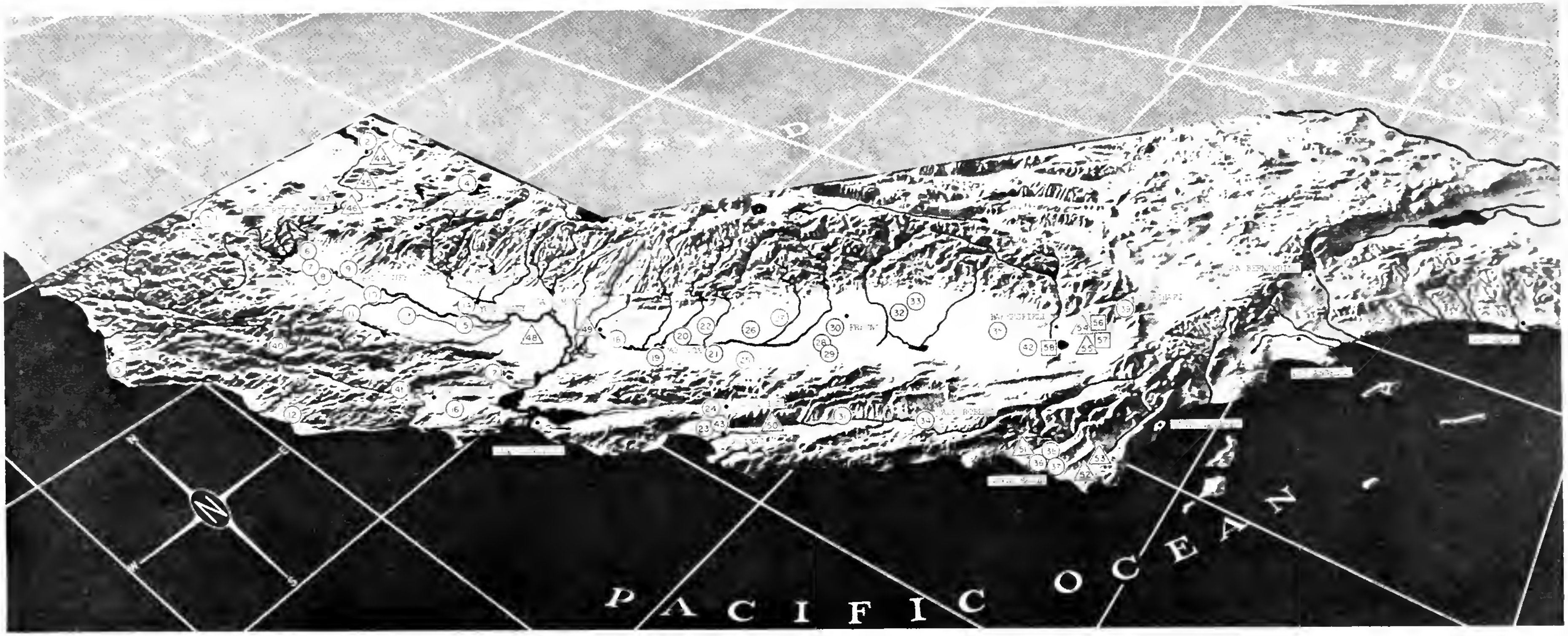
The evaporation rates from these devices are used as indices of the evaporative demand of the air and provide the basis for drawing boundaries around the areas of similar evaporative demand.

The availability of evaporation data obtained from evaporation pans and atmometers since 1955 for specific environments is shown in Figures 15, 16, and 17, Appendix B.

Agroclimatic Stations

Evaporation data are collected at agroclimatic stations established in representative agricultural areas throughout Northern and Central California, as shown in Figure 3. Each agroclimatic station is equipped with an evaporation pan, three pairs of Livingston black and white atmometers, a precipitation gage, and minimum and maximum air thermometers. A typical agroclimatic station is pictured in Illustration 1. The layout of a typical agroclimatic station is shown in Figure 4.

FIGURE 3



LOCATION OF AGROCLIMATIC AND EVAPOTRANSPIRATION STATIONS IN CENTRAL AND NORTHERN CALIFORNIA

AGROCLIMATIC STATIONS

Index No.	Name	Location1/	Crop
○	Operated during the whole or part of the period 1961 through 1964		
1.	Davis Creek	(2 WNW)	Pasture (improved)
2.	Cedarville	(2 ESE)	Pasture (improved)
3.	Montague	(3 NE)	Pasture (improved)
4.	Standish	(5 WNW)	Pasture (improved)
5.	Ferndale	(2 NW)	Pasture (nonirrigated)
6.	Bella Vista	(4 NE)	Dryland
7.	Redding	(6 SE)	Dryland
8.	Anderson	(4 E)	Pasture (improved)
9.	Red Bluff	(5 E)	Pasture (improved)
10.	Corning	(3 NE)	Pasture (improved)
11.	Newville	(1 E)	Dryland
12.	Elk	(4 SSE)	Pasture (nonirrigated)
13.	Willows	(6 S)	Dryland
14.	Yuba City	(7 W)	Pasture (improved)
15.	Arbuckle	(1 S)	Alfalfa
16.	Santa Rosa	(6 SSW)	Pasture (improved)
17.	Yountville	(2 N)	Pasture (improved)
18.	Stockton	(9 S)	Pasture (improved)
19.	Vernalis #2	(4 SE)	Pasture (improved)
20.	Ceres	(3 E)	Alfalfa
21.	Newman	(1 SE)	Pasture (improved)
22.	Atwater	(1 N)	Alfalfa
23.	Santa Rita	(2 W)	Pasture (improved)
24.	Hollister	(6 NNW)	Alfalfa
25.	Los Banos	(½ SW)	Gravel
26.	Merced	(5 SE)	Pasture (improved)
27.	Berenda	(2 N)	Pasture (improved)
28.	Mendota	(6 SW)	Alfalfa
29.	Mendota	(14½ SW)	Dryland
30.	Kerman	(2 ESE)	Pasture (improved)
31.	San Lucas	(½ S)	Alfalfa
32.	Kingsburg	(5 S)	Pasture (improved)
33.	Traver	(4 ESE)	Pasture (improved)
34.	Paso Robles	(4 N)	Pasture (improved)
35.	Pond	(1 N)	Pasture (improved)
36.	Guadalupe	(2 NNE)	Pasture (improved)
37.	Betteravia	(1½ NNE)	Pasture (improved)
38.	Santa Maria	(4 SE)	Pasture (improved)
39.	Tehachapi	(6½ SW)	Bluegrass
	Established Since 1964		
40.	Covelo	(1 E)	Pasture (improved)
41.	Geyserville	(½ E)	Pasture (improved)
42.	Buttonwillow	(1 SE)	Pasture (improved)
43.	Salinas	(4 NE)	Pasture (improved)

COMBINATION AGROCLIMATIC-EVAPOTRANSPIRATION STATIONS

△	Operated during the whole or part of the period 1961 through 1964		
44.	Alturas	(2 SE)	Pasture (meadow)
45.	Lookout	(3 S)	Pasture (meadow)
46.	Pittville	(1 S)	Alfalfa
47.	Glenburn	(DWR)	Pasture (improved)
48.	Davis2/	(1 W)	Ryegrass
49.	Thornton	(2 S)	Pasture (improved)
50.	Soledad	(4 NW)	Pasture (improved)
51.	Guadalupe	(2½ NNE)	Pasture (improved)
52.	Lompoc3/	(1 W)	Pasture (improved)
53.	Lompoc3/	(3 E)	Pasture (improved)
54.	Arvin	(2½ NW)	Fescue
	Established Since 1964		
55.	Arvin	(10 W)	Pasture (improved)

EVAPOTRANSPIRATION STATIONS

□	Operated during the whole or part of the period 1961 through 1964		
56.	-Arvin	(2½ NW)	Cotton
	-Arvin	(2½ NW)	Plums
	-Arvin	(2½ NW)	Alfalfa
	-Arvin	(2½ NW)	Potatoes
	-Arvin	(1 NW)	Grapes
57.	-Arvin	(4½ S)	Sugar Beets
	Established Since 1964		
58.	Buttonwillow	(3½ S)	Cotton

1/ The numbers and letters indicate the distance (in miles) and direction, respectively, from the community named.

2/ Operated by the Department of Water Science and Engineering, University of California, Davis.

3/ Operated 1959-61 by the Lompoc Field Station of the Agricultural Research Service, U. S. Department of Agriculture.

(The two agencies above hold research agreements with the Department)

Illustration I. A TYPICAL AGROCLIMATIC STATION IN A IRRIGATED PASTURE ENVIRONMENT

The marked effect of the immediate environment of the station on pan evaporation rates was clearly demonstrated in the early years of study. At stations in or adjacent to dryland areas, advective energy increased evaporation rates. In more recent years, stations have been established only on large, well-managed irrigated pastures to insure that evaporation rates would reflect only the average evaporative demand of the area and not be unduly influenced by border effects or advection extremes.

A few stations have been operated at various locations and at various times under alfalfa and dryland environments. This has been done when suitable pasture sites have not been available or to gain some knowledge of the magnitude of environmental effects on evaporation rates. Experience has shown, however, that pan data from these sites do not correlate as well with evapotranspiration data as do pan data obtained under standard pasture conditions. On the other hand, it has been found that net atmometer evaporation is much less strongly affected by the surrounding environment and correlates with evapotranspiration equally as well as pan evaporation. This observation indicates that atmometers may possess an important advantage over pans in measuring evaporative demand in an alfalfa or dryland environment.

Evaluation and Interpretation of Evaporative Demand Data

In analyzing the evaporative demand data, the agroclimatic stations were placed into groups having similar magnitudes and monthly distributions of evaporative demand. In Bulletin No. 113, the data were segregated by area designations which were arbitrary and, in general, principally geographic subdivisions. Additional years of data now allow a more thorough analysis.

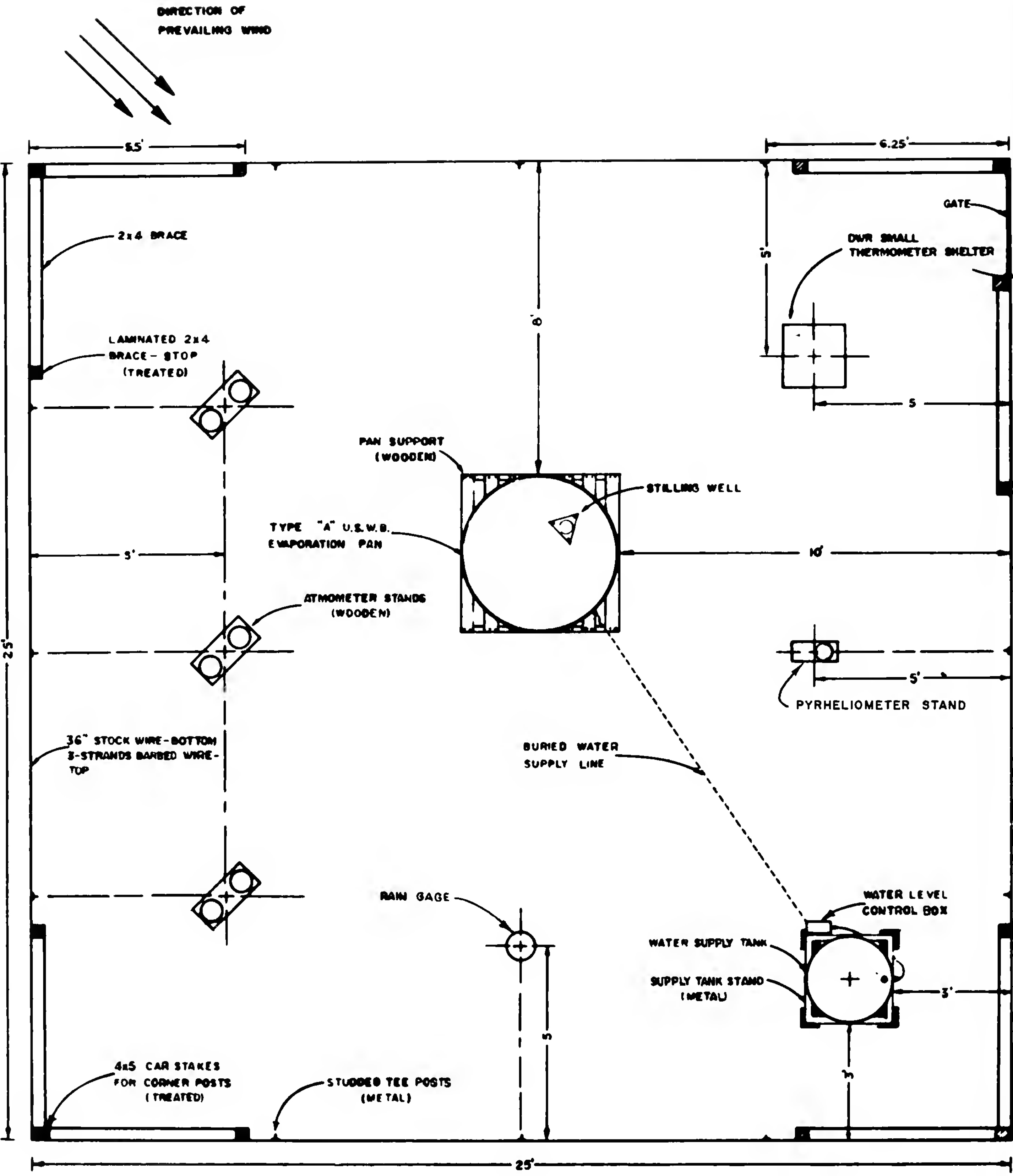


Figure 4
LAYOUT OF A TYPICAL AGROCLIMATIC STATION

SCALE OF FEET
0 2 4

Pan and Atmometer Evaporation Transect Data - Agroclimatic stations were initially established to determine the magnitude and variability of evaporative demand within the Central Valley, northeastern portion of the State, and in the central coastal area. Many of the stations were operated for only a short time because of changes in cropping patterns adjacent to the plots, insufficient irrigation, inadequate management of the plot areas, and, in some cases, lack of maintenance funds. An analysis of the evaporative demand records of individual stations in a given agroclimatic zone indicates that year to year variations of monthly values at any individual station can be as great as, or greater than, variations for any given year between stations. For this reason it was concluded that using a computed mean evaporative demand value for estimating evapotranspiration in a particular agroclimatic zone, is better than using the records of any individual station.

Both annual variations at a single station and variations between stations are the result of many complex factors. Annual variations can result from differences in the total energy received, either as direct solar radiation or through advection. Evaporation differences between stations are largely due to variations in small and large-scale climatic conditions which influence the quantity of advective energy received by a station.

Data from selected stations were plotted to form transects along the Central Valley and across the Coast Range. Location of these transects is shown on Figure 5.

Central Valley Transect - This transect runs along the floor of the Central Valley from Anderson in the north to Arvin in the south. Monthly pan evaporation data, collected during the period 1957 to 1964 at 20 different agroclimatic stations having irrigated pasture environments, are plotted on Plate 1. As can be noted, none of the stations were operated during the entire eight-year period. Because the seven stations listed on Figure 5 were operated during the five-year period 1960-64 and because they were well distributed along the transect, they were used as the basis for deriving mean monthly pan evaporation rates within the Central Valley floor. The five-year monthly pan means and their extremes are presented in Table 3.

The atmometer data collected at 19 different irrigated pasture stations between 1957 and 1965 are shown on Plate 2. Many of these stations were operated for only one or two years. Except for Davis, atmometer data were collected at each of the station noted on Figure 5. Data collected at these stations were used to compute the mean monthly net atmometer values for the Central Valley for the same period as were used to determine the mean pan evaporation. The net atmometer means and their extremes are presented in Table 4.

FIGURE 5

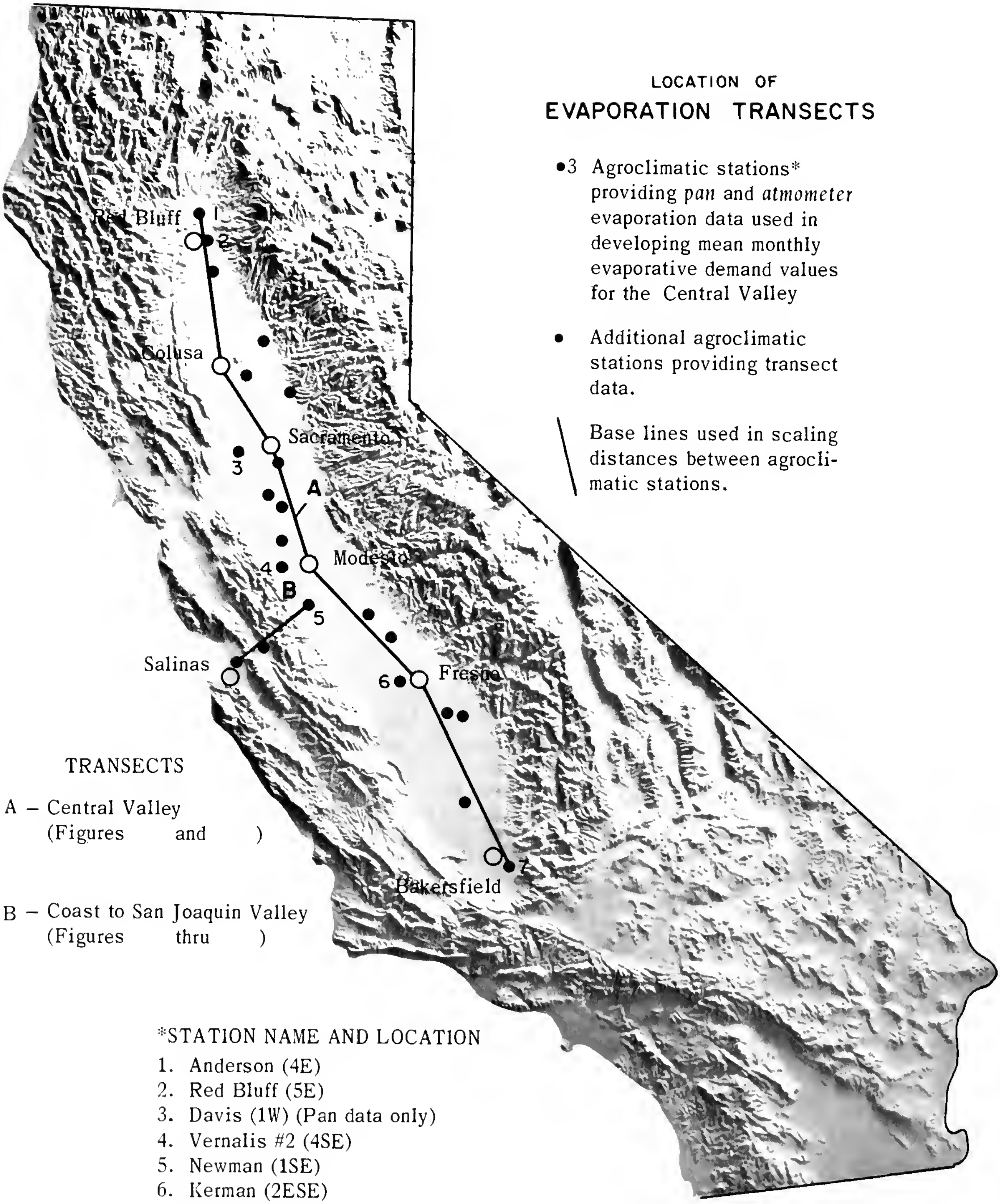

LOCATION OF
EVAPORATION TRANSECTS
•3 Agroclimatic stations* providing *pan* and *atmometer* evaporation data used in developing mean monthly evaporative demand values for the Central Valley
• Additional agroclimatic stations providing transect data.
Base lines used in scaling distances between agroclimatic stations.
Red Bluff
Colusa
Sacramento
Modesto
Salinas
Fresno
Bakersfield
A
B
1
2
3
4
5
6
7
TRANSECTS
A – Central Valley
(Figures and)
B – Coast to San Joaquin Valley
(Figures thru)
*STATION NAME AND LOCATION
1. Anderson (4E)
2. Red Bluff (5E)
3. Davis (1W) (Pan data only)
4. Vernalis #2 (4SE)
5. Newman (1SE)
6. Kerman (2ESE)
7. Arvin (2½NW)

Table 3
PAN EVAPORATION DATA-MEANS AND EXTREMES
FOR SELECTED STATIONS
CENTRAL VALLEY
1960-64

(in inches)
(USWB Pans in Irrigated Grass or Pasture)

Station	January			February			March			April		
	Mean	Low	High	Mean	Low	High	Mean	Low	High	Mean	Low	High
Anderson	1.4	0.7	2.3	2.3	1.6	3.4	3.5	3.0	3.8	5.6	4.7	6.2
Red Bluff	1.8	1.2	2.7	2.7	1.9	4.1	3.7	3.4	4.1	5.8	5.0	6.6
Davis	1.3	0.5	1.8	2.6	1.7	3.4	4.2	3.7	4.6	6.2	4.4	7.2
Vernalis #2	1.3	0.6	1.7	2.5	1.7	3.8	4.2	3.9	4.7	6.2	4.1	7.5
Newman	1.1	0.5	4.4	2.6	1.6	4.0	4.2	3.7	5.3	6.0	3.6	6.9
Kerman	1.0	0.8	1.3	2.2	1.7	2.6	4.2	4.1	4.5	6.1	4.8	6.9
Arvin	1.5	0.9	2.0	2.5	1.9	3.3	4.5	3.9	5.4	6.3	5.2	7.6
	1.4*			2.5*			4.0*			6.0*		

Station	May			June			July			August		
Anderson	6.5	6.0	6.9	8.5	7.8	9.3	9.9	9.5	10.4	8.1	7.2	9.7
Red Bluff	7.0	6.5	7.6	9.7	8.5	10.6	10.8	10.4	11.4	8.8	8.4	9.2
Davis	8.1	6.8	9.4	10.4	9.8	11.7	10.4	9.5	11.4	9.2	8.2	10.7
Vernalis #2	7.9	7.2	9.0	9.6	7.7	10.3	9.9	9.2	10.7	8.2	8.0	8.6
Newman	7.6	7.0	8.2	9.3	8.3	10.2	10.1	9.2	11.0	8.8	8.4	9.4
Kerman	8.3	7.9	9.2	9.6	8.4	10.1	9.5	8.0	11.0	8.4	7.4	9.6
Arvin	8.2	7.6	8.7	10.0	9.6	10.5	9.7	9.2	10.4	8.1	7.8	8.6
	7.6*			9.6*			10.0*			8.5*		

Station	September			October			November			December		
Anderson	6.3	5.8	6.9	3.7	3.3	4.0	2.2	1.6	3.5	1.5	0.9	2.2
Red Bluff	6.9	5.9	7.5	4.4	3.6	5.7	2.2	1.6	3.4	1.7	0.9	2.4
Davis	6.9	6.0	7.9	5.0	3.7	6.5	2.4	1.4	4.2	1.1	0.4	1.7
Vernalis #2	6.2	5.2	7.2	4.7	4.2	5.2	2.3	1.6	3.7	1.0	0.5	1.2
Newman	6.6	6.1	7.2	5.0	4.1	6.2	2.0	1.4	2.4	0.8	0.5	1.3
Kerman	6.2	6.0	6.8	4.4	3.6	5.4	2.0	1.6	2.4	0.9	0.4	1.2
Arvin	6.0	5.5	6.2	4.0	3.4	4.4	2.1	1.9	2.4	1.3	0.8	1.8
	6.4*			4.5*			2.2*			1.2*		

*Recommended 1960-64 mean values for all stations. Calculated by summing all monthly data and dividing by number of monthly values.

Table 4
NET ATMOMETER EVAPORATION DATA-MEANS AND EXTREMES
FOR SELECTED STATIONS
CENTRAL VALLEY
1960-64

(in milliliters)
(Livingston Atmometers in Irrigated Grass or Pasture)

Station	March			April			May			June		
	Mean	Low	High	Mean	Low	High	Mean	Low	High	Mean	Low	High
Anderson	248	211	284	342	288	380	455	404	537	543	508	572
Red Bluff	282	263	301	371	310	409	484	407	539	557	480	600
Vernalis #2	343	312	364	427	330	469	509	482	540	522	442	583
Newman	336	298	348	425	349	467	490	479	506	524	427	566
Kerman	344	313	372	427	373	457	474	462	490	498	460	536
Arvin	358	344	365	429	355	475	501	437	570	577	475	670
	330*			410*			485*			537*		
	July			August			September			October		
Anderson	586	519	656	521	466	633	417	360	472	298	244	343
Red Bluff	603	603	657	518	441	593	427	360	507	320	280	361
Vernalis #2	585	555	600	530	488	569	450	404	491	330	287	372
Newman	563	542	593	528	486	570	434	417	448	341	313	372
Kerman	544	494	604	513	479	530	430	395	456	349	325	366
Arvin	599	562	639	551	516	582	479	466	498	360	340	381
	580*			527*			440*			333*		

*Recommended five-year mean (1960-64) values for all stations. Calculated by summing all measured monthly data and dividing by number of measurements.

Although monthly evaporation rates during the period of record, generally, were quite similar between stations, large year-to-year differences in monthly evaporation did occur. An example is the evaporation observed in April 1963 which was approximately 33 percent less than the 1960-64 mean of all stations for that month.

Central Coast to San Joaquin Valley Transect - This transect of monthly pan evaporation extends from near the mouth of the Salinas Valley easterly into the San Joaquin Valley. The Santa Rita station, located 7 miles inland from the coast, is subject to immediate coastal climatic effects. The Hollister station is located in an alfalfa field in a central coastal valley environment. Although weekly pan data from a station established in an alfalfa environment might not compare favorably with pan data from a pasture environment, evaporation rates over periods of a month or longer generally are comparable. The Newman pasture site is typical of evaporation in the Central Valley.

In Figure 6 the 1963 and 1964 values, the only data available for each station, have been averaged and plotted. These limited data indicate some general trends. The graph shows higher summer evaporation rates in the San Joaquin Valley than on the coast and winter rates that apparently reverse this pattern. Figure 7 shows monthly transects of pan evaporation rates for each station.

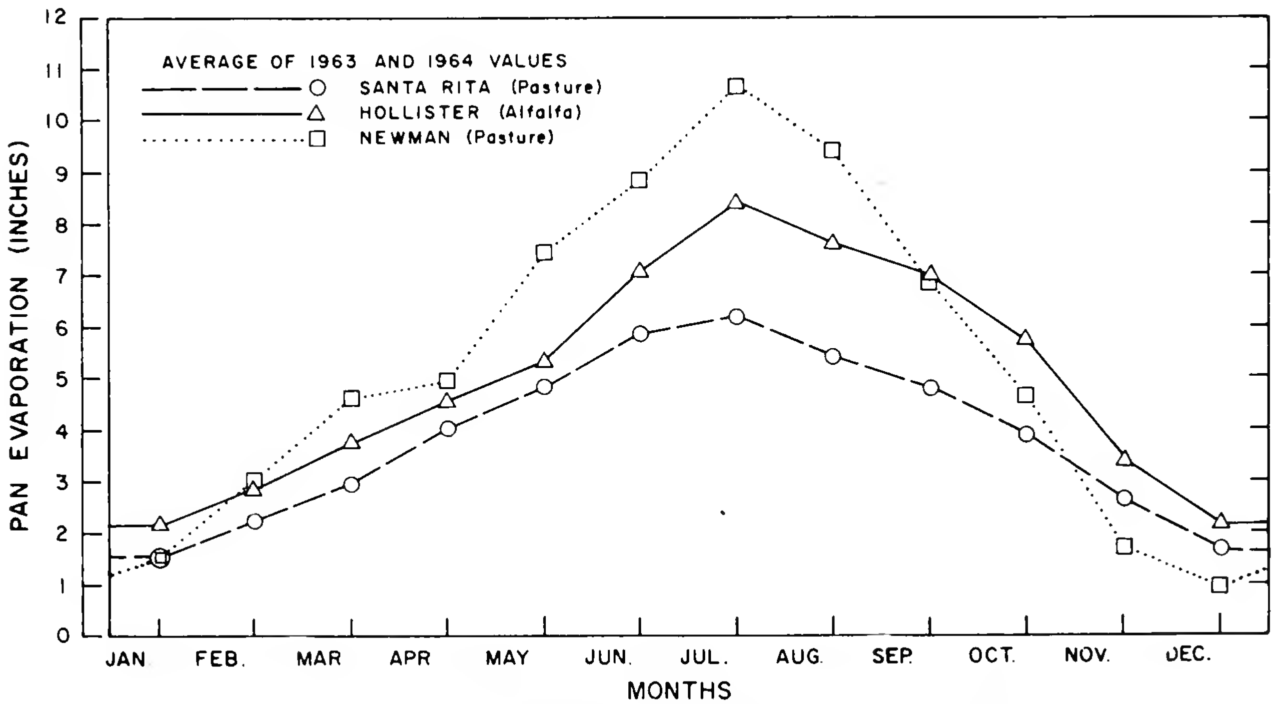
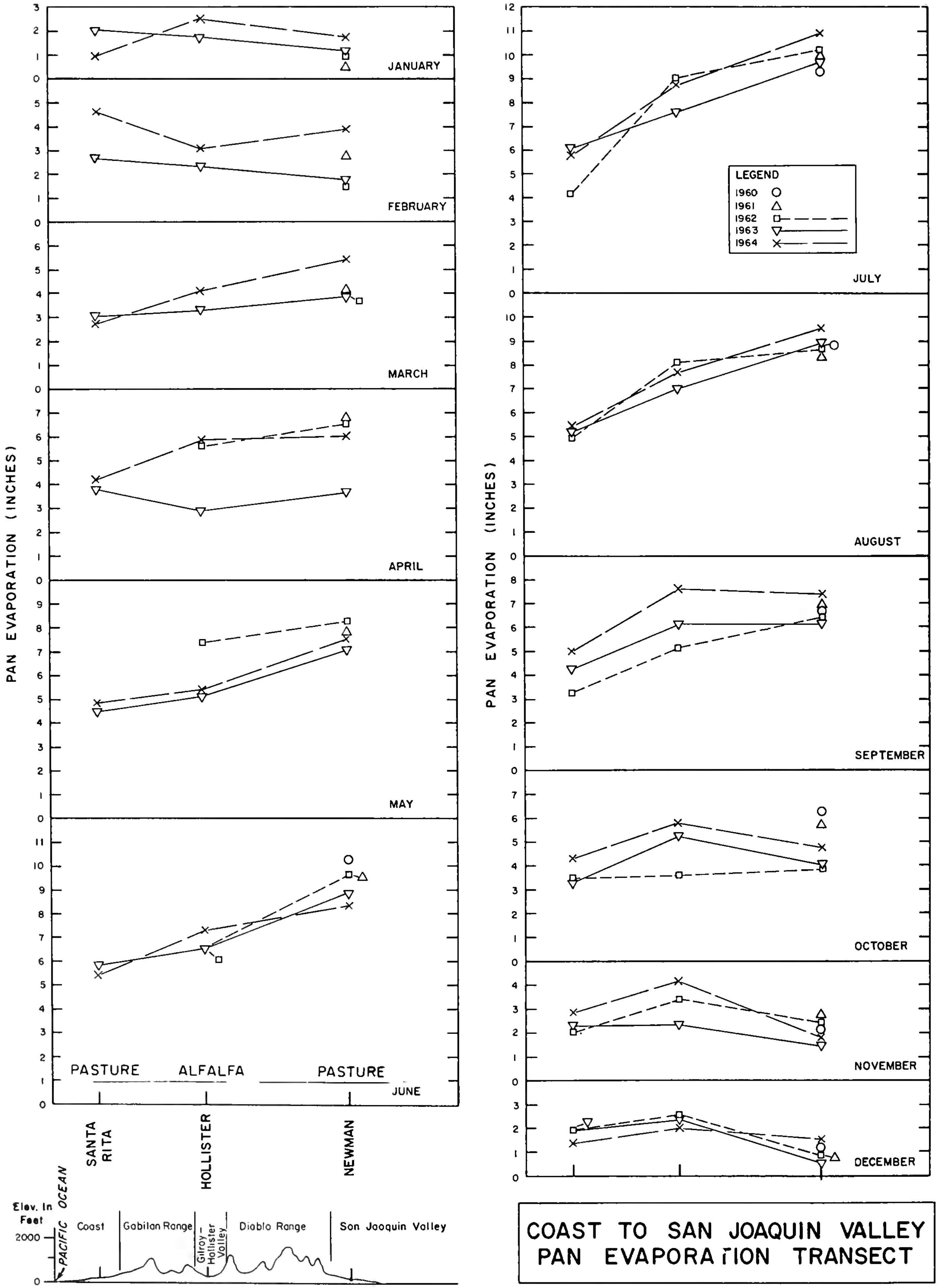


Figure 6. MONTHLY PAN EVAPORATION CENTRAL COAST, CENTRAL COASTAL VALLEYS, AND SAN JOAQUIN VALLEY



COAST TO SAN JOAQUIN VALLEY PAN EVAPORATION TRANSECT

This reversal during the winter is explained by the fact that coastal areas, because of less winter fog, receive more hours of sunlight and therefore higher energy levels than the Central Valley. During the balance of the year, however, evaporation rates near the coast are lower than at the other two stations because of the cool marine air and summer fog.

Evaporative Demand Zones

In addition to the data presented in the two transects discussed, data from all other stations have been analyzed. This analysis indicates that the principal agricultural areas of the northern and central part of the State can be divided into four distinctly different evaporative demand zones:

A. Central Coast - The fog belt area immediately adjacent to the coast, from south of San Luis Obispo to north of Fort Bragg.

B. Central Coastal Valleys - The valleys opening toward the ocean but inland from the predominant fog belt, from south of San Luis Obispo to north of Santa Rosa.

C. Central Valley - The floor of the Central Valley from south of Bakersfield to north of Redding.

D. Northeastern Mountain Valleys - The larger irrigated mountain valleys within the Klamath, Pit, and Susan River drainages.

These zones are shown on Figure 8.

In Table 5, average monthly and annual evaporation rates from pans and atmometers are shown for these four evaporative demand zones. These monthly data have been plotted in Figure 9 to illustrate the marked differences that occur between zones and to show the close relationship between evaporation rates and measurements of evapotranspiration within each zone. This relationship will be discussed in the following section. The evaporation curves shown in Figure 9 represent the best present estimates of evaporative demand within the major agricultural areas of Northern and Central California.

Evapotranspiration-Correlation Studies

Evapotranspiration measurements are being made of selected crops and correlated with evaporative demand values to provide a more accurate basis for estimating evapotranspiration rates of major crops anywhere in the State. The evapotranspiration measurements are made using ET tanks and radioactive neutron

probes. The ET tanks were used at evapotranspiration stations in the southern San Joaquin Valley, the Santa Maria Valley, the Salinas Valley, the Sacramento-San Joaquin Delta, and in two of the northeastern mountain valleys. Neutron probes were used in the southern San Joaquin Valley and in the northeastern mountain valley area. Illustration 2 shows a neutron probe being used to measure evapotranspiration of alfalfa. A summary of all evapotranspiration data collected under the program through 1964 is presented in Table 6.

Illustration 2. MEASURING EVAPOTRANSPIRATION WITH A RADIOACTIVE NEUTRON PROBE

The objectives of the evapotranspiration studies are based upon the hypothesis that evapotranspiration measurements of a crop can be correlated with evaporative demand measurements to provide a basis for estimating the evapotranspiration requirements of the same crop in other agroclimatic zones.

Initially, this hypothesis was tested by correlating evapotranspiration measurements of alfalfa with evaporative demand measurements determined by Livingston atmometers, as suggested by research conducted by Dr. F. J. Veihmeyer 1/ at

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1/ "Determining Water Needs for Crops from Climatic Data", N. A. Halkias, F. J. Veihmeyer, and A. H. Hendrickson, Hilgardia, Volume 24, No. 9, December 1955.

FIGURE 8

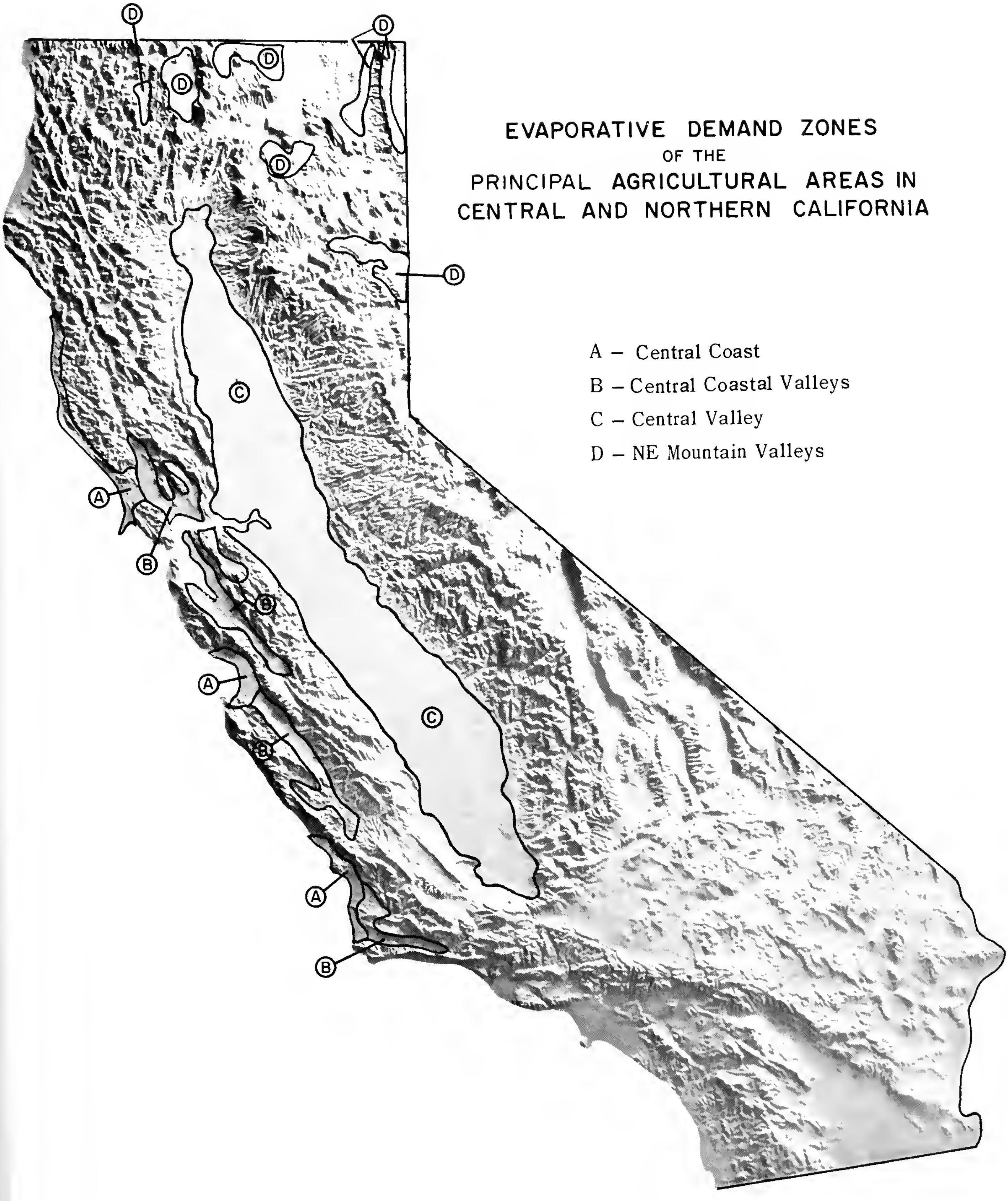

EVAPORATIVE DEMAND ZONES
OF THE
PRINCIPAL AGRICULTURAL AREAS IN
CENTRAL AND NORTHERN CALIFORNIA
A – Central Coast
B – Central Coastal Valleys
C – Central Valley
D – NE Mountain Valleys
A
B
C
D

Table 5
AVERAGE MEASURED MONTHLY POTENTIAL EVAPOTRANSPIRATION, PAN EVAPORATION, AND NET ATMOMETER EVAPORATION-BY MAJOR EVAPORATIVE DEMAND ZONES

ZONES	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL

POTENTIAL EVAPOTRANSPIRATION (INCHES)
Grass or Pasture

ZONES	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL
CENTRAL COAST	2.0	2.7	3.1	3.3	4.1	4.6	4.9	4.9	4.1	3.3	2.1	1.7	40.8
CENTRAL COASTAL VALLEYS	1.4	2.4	3.2	4.1	5.2	5.3	6.1	5.9	5.1	2.9	2.0	1.5	45.1
CENTRAL VALLEY	0.8	1.8	3.5	4.8	6.6	7.6	8.5	7.4	5.4	3.5	1.6	1.0	52.5
N.E. MTN. VALLEYS				2.7	4.2	5.8	7.4	8.8	4.6	2.8	0.6		

Stations and Period of Record

CENTRAL COAST	GUADALUPE 2½ N (63-65)
CENTRAL COASTAL VALLEYS	SOLEDAD (63-65)
CENTRAL VALLEY	DAVIS-CAMPBELL (59) DAVIS-PRUITT (59-64) THORNTON (63 & 64) ARVIN (61-64)
N.E. MTN. VALLEYS	GLENBURN (64 & 65)

PAN EVAPORATION (INCHES)

ZONES	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL
CENTRAL COAST	2.6	3.2	4.1	5.0	5.8	6.3	6.1	5.7	4.7	4.1	2.3	2.0	52.4
CENTRAL COASTALVALLEYS	2.6	3.2	4.3	5.6	7.0	7.7	8.7	7.6	6.1	4.9	3.1	2.3	63.1
CENTRAL VALLEY	1.4	2.5	4.0	6.0	7.6	9.6	10.0	8.5	6.4	4.5	2.2	1.2	63.9
N.E. MTN. VALLEYS	0.9	1.4	2.7	4.8	6.4	8.1	10.6	9.2	6.5	3.7	1.5	0.7	56.5

Stations and Period of Record

CENTRAL COAST	GUADALUPE 2½ N (63-65) GUADALUPE 2N (61-63) BETTERAVIA (61 & 62) SANTA RITA (62-64)
CENTRAL COASTAL VALLEYS	SOLEDAD (61-65) HOLLISTER* (62-64) SAN LUCAS* (62-64) SANTA MARIA (61-62)
CENTRAL VALLEY	1960-1964 7 STATION MEAN (SEE PLATE 1)
N.E. MTN. VALLEYS	MONTAGUE (59-64) GLENBURN (60-64) DAVIS CREEK (62-64) STANDISH (59-64)

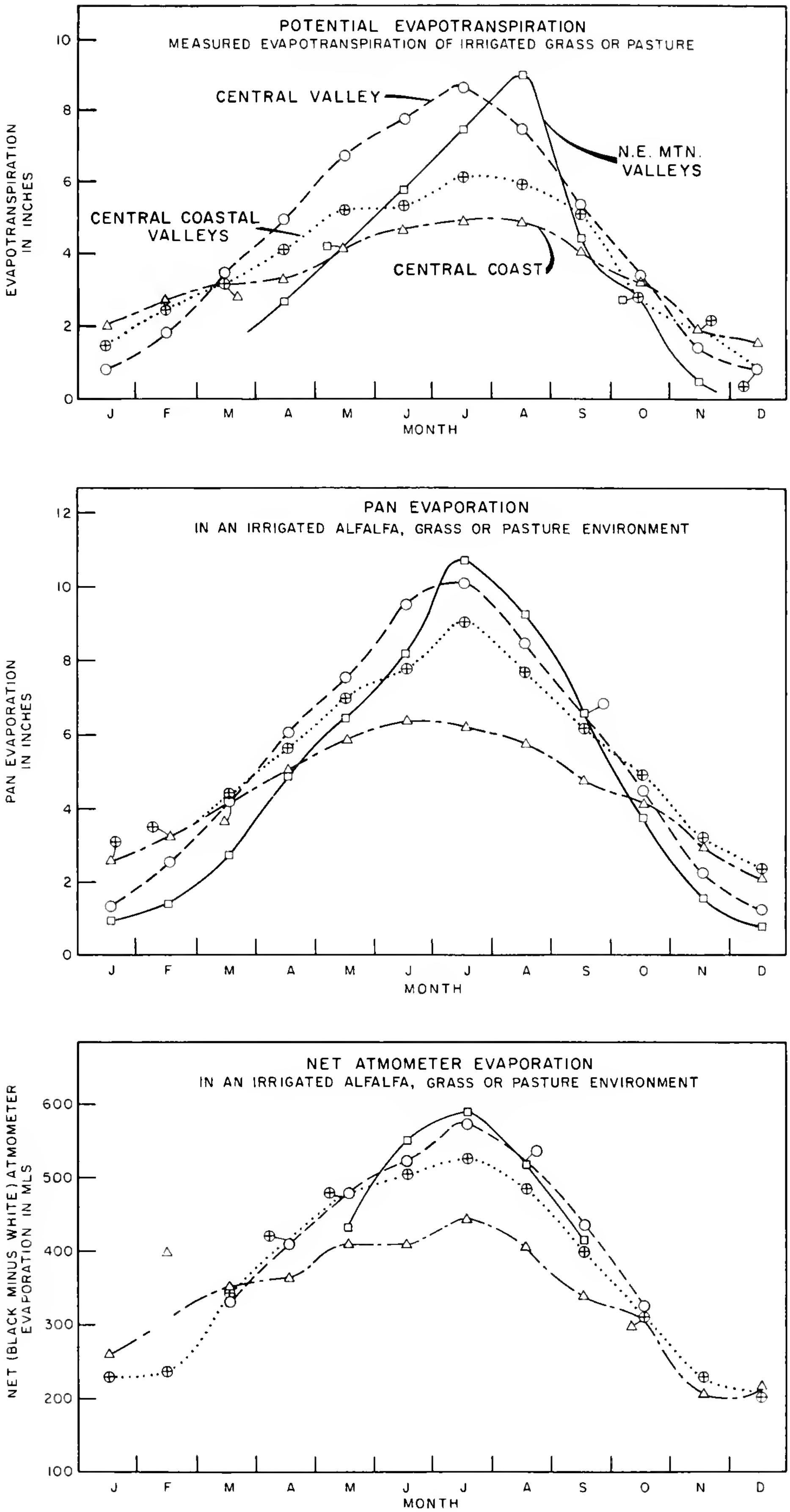
NET ATMOMETER EVAPORATION (MILLILITERS)

ZONES	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL
CENTRAL COAST	260	398	351	368	412	422	450	405	344	311	209	221	4151
CENTRAL COASTAL VALLEYS	221	218	349	424	479	504	528	489	403	317	236	218	4386
CENTRAL VALLEY			330	410	485	537	580	527	440	333			
N.E. MTN. VALLEYS					435	553	592	520	419				

Stations and Period of Record

CENTRAL COAST	GUADALUPE 2½N (63-65) GUADALUPE 2N (61-63) BETTERAVIA (61 & 62) SANTA RITA (62-64)
CENTRAL COASTAL VALLEYS	SOLEDAD (61-65) HOLLISTER* (62-64) SAN LUCAS* (62-64) SANTA MARIA (62)
CENTRAL VALLEY	1960-1964 6 STATION MEAN (SEE PLATE 2)
N.E. MTN. VALLEYS	MONTAGUE (59-61) GLENBURN (60-64) ALTURAS (59-64) FALL RIVER MILLS (59) LOOKOUT (59-63)

* Alfalfa Plots - other plots grass or pasture



AVERAGE MEASURED MONTHLY POTENTIAL EVAPOTRANSPIRATION, PAN EVAPORATION, AND NET ATMOMETER EVAPORATION— BY MAJOR EVAPORATIVE DEMAND ZONES

Table 6

MEASURED MONTHLY EVAPOTRANSPIRATION FOR GRASS AND PASTURE, COTTON, PLUMS AND ALFALFA

AGENCY [1]	STATION & LOCATION [2]	CROP	METHOD OF MEASUREMENT	YEAR	Evapotranspiration (in inches)												ANNUAL TOTAL	
					JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Inches	Ac Ft
DWR	Alturas 2SE	Pasture (meadow)	Inflow-Outflow ET Tanks	1959	-	-	-	5.2	6.0	9.0	10.4	9.0	4.9	2.8	-	-	-	-
				1960	-	-	-	3.0	4.8	6.6	9.6	9.3	6.0	3.6	0.5	0.8	-	-
				1961	0.2	0.7	2.0	4.7	6.6	8.3	10.2	7.3	6.6	3.1	-	-	50.9	4.2
				1962	-	-	0.8	4.4	4.8	7.4	8.6	8.4	5.9	2.3	1.1	1.6	45.5	3.8
				1963	0.5	0.4	1.3	1.6	3.5	5.7	7.3	7.6	4.7	3.0	-	-	-	-
				1964	-	-	-	2.4	3.9	5.0	8.1	8.5	5.0	3.1	-	-	-	-
DWR	Lookout 3S	Pasture (meadow)	Inflow-Outflow ET Tanks	1961	0.2	0.3	1.0	3.8	5.1	7.8	9.0	7.4	6.0	3.0	-	-	-	-
				1962	0.3	0.5	1.0	3.8	5.5	7.1	8.5	8.0	5.8	2.3	1.0	0.5	44.3	3.7
				1963	-	-	1.4	-	-	6.4	9.5	8.7	4.8	3.8	-	-	-	-
DWR	Coleville 2E	Pasture (meadow)	Floating ET Tanks	1957	-	-	-	-	-	7.5	9.1	7.8	-	-	-	-	-	-
DWR	Glenburn (DWR)	Pasture (improved)	Floating ET Tanks	1964	-	-	-	2.9	4.4	5.6	6.6	8.5	5.1	2.5	-	-	-	-
				1965	-	-	-	2.6	6.0	5.6	6.9	7.3	4.9	3.3	0.8	-	-	-
DWR	Thornton 2S	Pasture (improved)	Floating ET Tanks	1963	-	-	-	-	-	-	-	-	5.2	2.2	0.6	.4	-	-
				1964	0.6	1.1	2.8	6.3	8.6	7.7	9.8	6.7	4.5	3.1	.9	0.5	52.6	4.4
				1965	-	2.1	2.2	3.4	7.4	7.4	8.3	6.6	4.0	2.3	-	0.7	-	-
DWR & SLOCFC	Guadalupe 2½NNE	Pasture (improved)	Floating ET Tanks	1963	-	-	-	-	-	-	4.4	4.7	4.3	3.0	2.5	2.3	-	-
				1964	1.9	2.6	2.7	3.6	3.3	4.0	4.7	4.2	3.8	2.8	1.8	1.3	36.6	3.0
				1965	2.1	2.7	3.5	3.1	4.9	5.2	5.5	5.8	4.2	4.2	2.0	1.5	44.7	3.7
DWR	Soledad 4NW	Pasture (improved)	Weighing ET Tanks	1963	-	-	-	4.0	5.0	5.3	6.4	6.3	4.8	3.4	2.0	1.6	-	-
				1964	1.4	2.6	3.4	4.4	5.8	5.6	6.0	5.4	5.3	2.4	2.1	1.4	45.8	3.8
				1965	1.5	2.3	3.0	3.8	4.8	4.8	5.9	-	-	-	-	-	-	-
ARS	Lompoc 1W	Pasture (improved)	Neutron Probe	1959	-	-	-	-	-	4.1	3.4	4.8	3.6	3.6	4.1	1.7	-	-
				1960	1.8	2.3	2.6	3.1	4.7	-	-	-	-	-	-	-	-	-
ARS	Lompoc 3E	Pasture (improved)	Neutron Probe	1958	-	-	-	-	-	7.1	4.9	4.7	4.5	3.7	2.2	1.9	-	-
				1959	-	-	-	4.6	5.4	3.5	5.7	3.1	2.6	2.9	2.8	1.5	-	-
				1960	1.8	2.7	2.4	4.7	3.3	-	-	-	-	-	-	-	-	-
DWR	Davis (Campbell) 1W	Grass	Weighing ET Tanks	1959	1.2	2.6	4.3	4.4	6.0	7.4	8.7	7.0	6.0	4.6	1.9	1.2	55.3	4.6
				1960	.9	1.8	3.1	5.3	7.1	5.9	-	-	-	-	-	-	-	-
UC at Davis	Davis (Pruitt) 1W	Grass	Weighing ET Tanks	1959	-	-	-	-	-	-	8.9	7.3	5.8	4.4	2.2	1.4	-	-
				1960	1.2	2.4	3.8	5.3	6.8	8.7	8.4	6.7	5.2	3.8	1.7	1.2	55.2	4.6
				1961	.6	2.3	3.4	4.8	6.6	8.3	8.6	8.6	5.0	3.5	1.9	0.9	54.5	4.5
				1962	1.1	1.4	3.0	5.1	6.5	8.1	8.2	6.9	4.9	3.1	1.7	.8	50.8	4.2
				1963	0.7	1.8	2.4	3.9	5.5	8.2	8.2	6.6	4.6	2.9	1.4	0.6	46.8	3.9
				1964	-	-	-	-	-	6.6	8.4	7.7	6.4	3.9	1.5	1.2	-	-
DWR	Arvin 2½NW	Grass	Neutron Probe	1961	.6	2.5	4.1	5.1	5.7	7.0	7.0	8.4	5.4	4.3	1.5	1.0	52.6	4.4
				1962	0.8	1.0	3.9	5.5	6.1	7.0	8.6	7.4	6.3	2.6	1.5	1.0	51.4	4.3
				1963	.2	1.5	3.7	3.8	7.9	8.3	7.6	6.8	5.1	2.7	2.2	0.4	50.2	4.2
				1964	1.0	1.9	3.2	3.5	6.0	6.8	8.5	7.9	5.9	3.8	1.8	1.4	51.7	4.3
DWR	Arvin 2½NW	Cotton (solid)	Neutron Probe	1959	-	-	-	-	1.6	7.5	10.7	7.8	5.1	3.0	.2	-	-	-
				1960	-	-	1.1	0.8	0.3	5.3	10.1	8.9	5.0	1.0	1.0	0.4	-	-
				1961	.4	1.4	1.1	.4	1.1	5.5	8.6	8.2	5.7	2.4	.7	0.4	35.9	3.0
		(Skip row) 2in-2out 2in-1out		1962	0.6	0.6	1.0	1.1	.7	3.9	9.1	7.9	5.0	1.6	0.3	-	31.8	2.6
				1963	.1	.8	1.2	1.5	1.6	4.7	8.8	8.3	4.8	2.6	0.4	0.2	35.0	2.9
DWR	Arvin 2½NW	Plums	Neutron Probe	1959	-	-	-	3.6	6.0	6.4	8.1	6.5	2.5	1.0	0.1	-	-	-
				1960	-	-	-	-	-	8.2	8.7	6.4	4.7	1.4	0.4	-	-	-
				1962	.6	1.3	1.1	2.7	5.1	6.5	6.9	4.1	4.1	3.4	2.0	.6	38.4	3.2
				1963	0.7	1.7	3.0	4.8	5.4	5.9	6.7	7.0	5.2	2.8	1.6	0.3	45.1	3.8
				1964	0.8	1.1	-	-	-	5.6	7.6	7.0	5.7	3.8	0.6	.9	-	-
DWR	Pittville 1S	Alfalfa	Neutron Probe	1959	-	-	-	5.9	6.8	6.9	9.0	6.2	6.9	-	-	-	-	-
				1960	-	-	-	2.8	6.4	5.6	8.4	8.9	5.1	3.8	-	-	-	-
				1961	-	-	0.8	4.4	5.4	6.5	-	6.6	5.1	2.1	0.5	.1	-	-
				1962	-	-	-	4.6	6.0	6.7	6.4	5.5	7.0	-	-	-	-	-
DWR	Arvin 2½NW	Alfalfa	Neutron Probe	1959	-	-	-	4.5	4.5	5.8	6.3	6.1	5.3	3.2	2.8	1.9	-	-
				1960	-	-	-	-	-	7.7	6.0	6.6	4.1	2.6	-	-	-	-
				1963	1.8	2.1	3.9	3.8	6.3	7.0	8.3	7.0	4.7	3.1	1.4	0.8	50.2	4.2

1/ Measurements made by the Department of Water Resources, the San Luis Obispo County Flood Control and Water Conservation District, the Agricultural Research Service, and the University of California at Davis.

2/ Locations represented by numbers and letters indicate the distance (in miles) and direction, respectively, from the community named. Thus, "Alturas 2SE" refers to a station 2 miles southeast of the town of Alturas.

the University of California at Davis. However, due to the variability of evapotranspiration rates resulting from changing ground cover conditions following mowing and regrowth of the alfalfa, it was difficult to obtain comparable results either within a single agroclimatic zone or between different zones. Because well-managed grass or pasture crops provide near 100 percent ground cover throughout the year, these crops have more recently been selected as the standard crops for evapotranspiration comparisons.

A distinct advantage to using grass is that evapotranspiration of grass is defined in the literature as a measure of "potential evapotranspiration" (PET) 2/. Potential evapotranspiration is defined as the evapotranspiration rate of a large, well-watered, low-growing crop at full ground cover, and of about the same color as grass. A large size is necessary to minimize advective effects; the crop must be well-watered to assure that the evapotranspiration rate is not affected by soil moisture stress; full ground cover assures that the evapotranspiration rate is not reduced because of reduction in transpiring surface; a low-growing crop provides a smooth surface, thereby reducing the effect of intermixing of air above the crop; and a crop color similar to that of grass assures a uniform albedo or reflectance of the crop. It is assumed that large, well-managed irrigated pastures and grassed areas meet these requirements.

Evapotranspiration-Correlation Measurements

Presented in this section are the results of studies made to correlate field measurements of evapotranspiration with evaporation for grass and pasture, alfalfa, cotton, deciduous orchard (plums), and meadow pasture (native pasture with water table close to surface).

Grass and Pasture - Measurements of PET were made by the Department at five different grass and pasture locations representing all four evaporative demand zones. The sites are shown on Figure 3 (index numbers 47, 49, 50, and 54). In addition to the sites operated by the Department, the University of California at Davis operates a 20-foot-diameter, grass-covered, weighing lysimeter (index number 48) as part of the research project partially sponsored by the Department. Because the University's data are measured precisely with very sensitive equipment, they are used as the standard to which all DWR pasture potential evapotranspiration data are compared.

2/ "Natural Evaporation from Open Water, Bare Soil, and Grass", H. L. Penman, Proc. Roy. Soc. London A193: 120-45, 1948.

At each of the five sites, evapotranspiration tanks were used for making potential evapotranspiration measurements. Illustration 3 shows various steps in the installation of an evapotranspirometer.

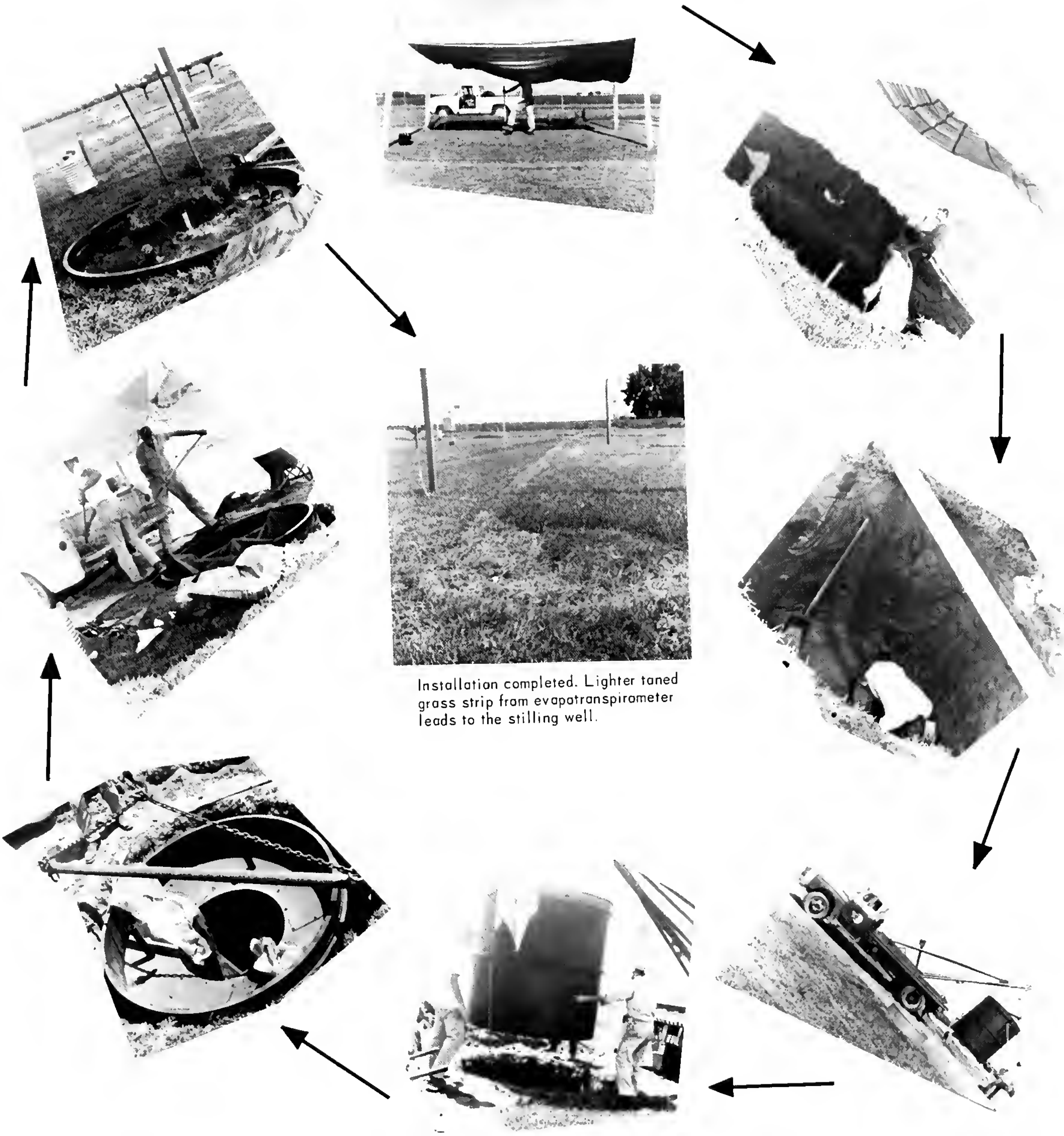
Averages of all monthly potential evapotranspiration data in each evaporative demand zone (Table 3 and Figure 9) show the relationship of potential evapotranspiration to average values of pan and atmometer evaporation for the same zones. A summary of all monthly evapotranspiration, pan and atmometer data, and ET/Ep and ET/Eb-w ratios is presented in Table 7. Both pan and atmometer evaporation data were collected at the Department's sites. Only pan evaporation data were collected at the Davis site.

Meadow Pasture - Meadow pasture evapotranspiration has been measured in two locations in the northeastern mountain valleys. There has been considerable question whether the evapotranspiration rate from a high-water table pasture would equal or exceed the evapotranspiration rate from improved pasture. Results to date, while not conclusive, seem to indicate that the rate for meadow pasture may be somewhat higher than for improved pasture. Table 8 presents a monthly summary of evapotranspiration data, evaporation data, and the computed ratios of evapotranspiration to evaporative demand.

Alfalfa - Alfalfa was the first crop used for correlating measurements of evapotranspiration with evaporative demand. Because alfalfa is frequently mowed, its ground cover may vary from less than 5 percent immediately following cutting to nearly full cover (95-100 percent) immediately prior to mowing. The period from mowing to mowing is approximately 30 days in the Central Valley and approximately 45 days in the northeastern mountain valleys. During this period, the evapotranspiration rate increases, reaching a maximum rate around 50-60 percent ground cover.

While the ground cover for any one field may vary from near zero to 100 percent, alfalfa lands within any large area reflect a more consistent "average" ground cover condition. For any particular day during the alfalfa growing season, every stage of crop development from "just-mowed" through "ready-to-mow" can be observed. For this reason, the average evapotranspiration rates determined by the studies are reasonable approximations of the evapotranspiration demands of a large area. Alfalfa evapotranspiration data along with their corresponding coefficients, are presented in Table 9.

To supplement the evapotranspiration measurements of alfalfa in the Bakersfield area irrigation water applications to a plot were measured for a two-year period using a totalizing



Installation completed. Lighter toned grass strip from evapotranspirometer leads to the stilling well.

Illustration 3
INSTALLATION OF A FLOATING EVAPOTRANSPIROMETER

Table 7

GRASS AND PASTURE

Monthly Summary

EVAPOTRANSPIRATION (ET), EVAPORATION (E), and ET/E RATIOS

(Bakersfield Area)

1961 - 1964

GRASS

MONTH	EVAPOTRANSPIRATION (Inches)					PAN EVAPORATION (Inches)					NET ATMOMETER EVAPORATION (Milliliters)					PAN COEFFICIENTS ET/Ep					ATMOMETER COEFFICIENTS ET/Eb-w				
	1961	1962	1963	1964	AVE	1961	1962	1963	1964	AVE	1961	1962	1963	1964	AVE	1961	1962	1963	1964	AVE1/	1961	1962	1963	1964	AVE1/
JAN	0.6	0.8	0.2	1.0	0.6	0.9	1.6	1.8	1.5	1.4	-	-	-	-	-	0.67	0.50	0.11	0.67	0.43	-	-	-	-	-
FEB	2.5	1.0	1.5	1.9	1.7	2.6	1.9	2.4	3.3	2.6	-	-	-	-	-	0.96	0.53	0.63	0.58	0.65	-	-	-	-	-
MAR	4.1	3.9	3.7	3.2	3.7	3.9	4.3	5.4	4.5	4.5	364	344	365	363	359	1.05	0.91	0.69	0.71	0.82	0.0113	0.0113	0.0101	0.0087	0.0103
APR	5.1	5.5	3.8	3.5	4.5	6.6	7.6	5.2	6.1	6.4	475	444	355	437	428	0.77	0.72	0.73	0.57	0.70	0.0107	0.0124	0.0107	0.0080	0.0105
MAY	5.7	6.1	7.9	6.0	6.4	7.6	8.6	8.1	8.2	8.1	504	500	437	501	486	0.75	0.71	0.98	0.73	0.79	0.0113	0.0122	0.0181	0.0120	0.0132
JUN	7.0	7.0	8.3	6.8	7.3	9.9	10.5	9.6	9.8	10.0	610	601	475	525	553	0.71	0.67	0.86	0.69	0.73	0.0114	0.0116	0.0175	0.0130	0.0132
JUL	7.0	8.6	7.6	8.5	7.9	9.6	10.4	9.7	9.2	9.7	610	622	562	545	585	0.73	0.83	0.78	0.92	0.81	0.0114	0.0138	0.0135	0.0156	0.0135
AUG	8.4	7.4	6.8	7.9	7.6	7.8	8.6	7.8	8.1	8.1	529	576	551	531	547	1.07	0.86	0.87	0.98	0.94	0.0158	0.0128	0.0123	0.0149	0.0139
SEP	5.4	6.3	5.1	5.9	5.7	6.2	6.0	5.5	6.0	5.9	485	498	465	470	480	0.87	1.05	0.93	0.99	0.97	0.0111	0.0127	0.0110	0.0123	0.0119
OCT	4.3	2.6	2.7	3.8	3.4	4.4	3.9	3.4	4.3	4.0	350	355	340	376	355	0.98	0.67	0.79	0.88	0.85	0.0123	0.0073	0.0079	0.0101	0.0096
NOV	1.5	1.5	2.2	1.8	1.7	2.4	2.2	2.0	1.9	2.1	-	-	-	-	-	0.63	0.68	1.10	0.95	0.81	-	-	0.0092	0.0060	0.0074
DEC	1.0	1.0	0.4	1.4	0.9	1.2	1.8	0.8	1.5	1.3	-	-	-	-	-	0.83	0.56	0.50	0.93	0.69	-	-	-	-	-
ANNUAL	52.6	51.7		51.7	51.4	63.1	67.4	61.7	64.4	64.1	-	-	-	-	-	0.83	0.77		0.80		-	-	-	-	-

1/ Average coefficients determined by dividing sum of ET's by sum of E's.

(Delta Region near Thornton)

1963-1965

PASTURE

MONTH	EVAPOTRANSPIRATION (Inches)				PAN EVAPORATION (Inches)				NET ATMOMETER EVAPORATION (Milliliters)				PAN COEFFICIENTS ET/Ep				ATMOMETER COEFFICIENTS ET/Eb-w			
	1963	1964	1965	AVE	1963	1964	1965	AVE	1963	1964	1965	AVE	1963	1964	1965	AVE1/	1963	1964	1965	AVE1/
JAN	-	0.6	-	-	-	0.8	-	-	-	-	-	-	-	0.74	-	-	-	-	-	-
FEB	-	1.1	2.1	1.6	-	3.0	2.0	2.5	-	-	-	-	-	0.37	1.05	0.64	-	-	-	-
MAR	-	2.8	2.2	2.5	-	4.5	2.9	3.7	-	-	-	-	-	0.62	0.76	0.68	-	-	-	-
APR	-	6.3	3.4	4.8	-	6.3	4.1	5.2	-	421	366	394	-	1.00	0.82	0.92	-	0.0150	0.0093	0.0122
MAY	-	8.6	7.4	8.0	-	6.6	7.6	7.1	-	509	511	510	-	1.30	0.97	1.13	-	0.0169	0.0145	0.0157
JUN	-	7.7	7.4	7.5	-	7.9	8.6	8.2	-	512	545	528	-	0.97	0.86	0.91	-	0.0150	0.0136	0.0142
JUL	-	9.8	8.3	9.0	-	10.4	11.0	10.7	-	574	580	577	-	0.94	0.75	0.85	-	0.0171	0.0143	0.0156
AUG	-	6.7	6.6	6.6	-	9.8	8.9	9.4	-	500	505	502	-	0.68	0.75	0.70	-	0.0134	0.0131	0.0131
SEP	5.2	4.5	4.0	4.6	5.6	6.9	5.8	6.1	398	428	437	421	0.94	0.65	0.70	0.75	0.0131	0.0104	0.0092	0.0109
OCT	2.2	3.1	2.3	2.5	3.6	4.1	3.6	3.8	339	344	375	353	0.62	0.76	0.64	0.66	0.0065	0.0090	0.0061	0.0071
NOV	0.6	0.9	-	0.7	1.3	1.9	-	1.6	130	-	-	-	0.46	0.47	-	0.44	-	-	-	-
DEC	0.4	0.5	0.7	0.5	0.5	1.4	0.8	0.9	68	-	-	-	0.81	0.36	0.88	0.56	-	-	-	-
ANNUAL	-	52.6	-	-	-	63.6	-	-	-	-	-	-	-	0.83	-	-	-		-	-

1/ Average coefficients determined by dividing sum of ET's by sum of E's.

(Sacramento Valley near Davis) 1/

1959-1964

GRASS

MONTH	EVAPOTRANSPIRATION (Inches)							PAN EVAPORATION (Inches)							PAN COEFFICIENTS ET/Ep						
	1959	1960	1961	1962	1963	1964	AVE	1959	1960	1961	1962	1963	1964	AVE	1959	1960	1961	1962	1963	1964	AVE2/
JAN	1.2	1.2	0.6	1.1	0.7	-	1.0	1.6	1.8	0.5	1.8	1.0	-	1.3	0.75	0.67	1.20	0.61	0.70	-	0.77
FEB	2.6	2.4	2.3	1.4	1.8	-	2.1	2.6	3.4	2.9	1.7	2.3	-	2.6	1.00	0.71	0.79	0.82	0.78	-	0.81
MAR	4.3	3.8	3.4	3.0	2.4	-	3.4	6.3	4.6	4.6	3.7	4.2	-	4.7	0.68	0.83	0.74	0.81	0.57	-	0.72
APR	4.4	5.3	4.8	5.1	3.9	-	4.7	7.6	7.2	6.5	6.8	4.4	-	6.5	0.58	0.74	0.74	0.75	0.89	-	0.72
MAY	6.0	6.8	6.6	6.5	5.5	-	6.3	9.8	9.4	8.1	8.1	6.8	-	8.4	0.61	0.72	0.81	0.80	0.81	-	0.75
JUN	7.4	8.7	8.3	8.1	8.2	6.6	7.9	11.0	11.7	10.0	9.8	10.3	8.7	10.2	0.67	0.74	0.83	0.83	0.80	0.76	0.77
JUL	8.9	8.4	8.6	8.2	8.2	8.4	8.4	11.2	11.4	10.7	9.5	9.9	10.4	10.5	0.79	0.74	0.80	0.86	0.83	0.81	0.80
AUG	7.3	6.7	8.6	6.9	6.6	7.7	7.3	9.2	9.1	10.7	8.6	8.2	9.5	9.2	0.79	0.74	0.80	0.80	0.80	0.81	0.79
SEP	5.8	5.2	5.0	4.9	4.6	6.4	5.3	8.2	7.4	7.0	6.1	6.0	7.9	7.1	0.71	0.70	0.71	0.80	0.77	0.81	0.75
OCT	4.4	3.8	3.5	3.1	2.9	3.9	3.6	7.2	6.5	5.9	4.1	3.7	4.9	5.4	0.61	0.58	0.59	0.76	0.78	0.80	0.67
NOV	2.2	1.7	1.9	1.7	1.4	1.5	1.7	3.6	2.4	4.2	2.1	1.4	1.7	2.6	0.61	0.71	0.45	0.81	1.00	0.88	0.65
DEC	1.4	1.2	0.9	0.8	0.6	1.2	1.0	3.0	1.7	1.1	0.8	0.4	1.6	1.4	0.47	0.71	0.82	1.00	1.50	0.75	0.71
ANNUAL	55.9	55.2	54.5	50.8	46.8	-	52.7	81.3	76.6	72.2	63.1	58.6	-	69.9	0.69	0.72	0.75	0.80	0.80	-	0.75

1/ Provided by Mr. W. O. Pruitt, University of California at Davis

2/ Average coefficients determined by dividing sum of ET's by sum of E's

Table 7 (Cont.)

GRASS AND PASTURE

Monthly Summary

EVAPOTRANSPIRATION (ET), EVAPORATION (E), and ET/E RATIOS

(Santa Maria Valley Area)

1963 – 1965

PASTURE

MONTH	EVAPOTRANSPIRATION (Inches)				PAN EVAPORATION (Inches)				NET ATMOMETER EVAPORATION (Milliliters)				PAN COEFFICIENTS ET/Ep				ATMOMETER COEFFICIENTS ET/Eb-w			
	1963	1964	1965	AVE	1963	1964	1965	AVE	1963	1964	1965	AVE	1963	1964	1965	AVE 1/	1963	1964	1965	AVE 1/
JAN	-	1.9	2.1	2.0	-	3.1	2.3	2.7	-	-	-	-	-	0.61	0.91	0.74	-	-	-	-
FEB	-	2.6	2.7	2.7	-	3.8	3.3	3.5	-	-	-	-	-	0.68	0.82	0.77	-	-	-	-
MAR	-	2.7	3.5	3.1	-	4.5	4.1	4.3	-	-	-	-	-	0.60	0.85	0.72	-	-	-	-
APR	-	3.6	3.1	3.3	-	4.7	3.7	4.2	-	395	349	372	-	0.76	0.84	0.78	-	0.0091	0.0089	0.0089
MAY	-	3.3	4.9	4.1	-	5.2	5.8	5.5	-	402	409	406	-	0.63	0.84	0.74	-	0.0082	0.0120	0.0101
JUN	-	4.0	5.2	4.6	-	6.4	5.7	6.1	-	413	342	378	-	0.63	0.91	0.75	-	0.0097	0.0152	0.0122
JUL	4.4	4.7	5.5	4.9	5.9	6.2	5.8	6.0	480	464	428	457	0.75	0.76	0.95	0.82	0.0092	0.0101	0.0128	0.0107
AUG	4.7	4.2	5.8	4.9	5.4	5.5	5.7	5.5	420	411	452	428	0.87	0.76	1.02	0.89	0.0112	0.0105	0.0131	0.0114
SEP	4.3	3.8	4.2	4.1	4.7	4.5	4.8	4.6	367	369	362	366	0.91	0.84	0.88	0.89	0.0117	0.0103	0.0116	0.0112
OCT	3.0	2.8	4.2	3.3	3.8	3.4	4.4	3.9	313	303	363	326	0.79	0.79	0.95	0.85	0.0096	0.0089	0.0116	0.0101
NOV	2.5	1.8	2.0	2.1	2.7	2.6	2.0	2.4	267	257	242	255	0.93	0.69	1.00	0.87	0.0094	0.0070	0.0083	0.0082
DEC	2.3	1.3	1.5	1.7	2.2	2.4	1.7	2.1	-	-	-	-	1.04	0.54	0.88	0.81	-	-	-	-
ANNUAL	-	36.6	44.7	40.8	-	52.3	49.3	50.8	-	-	-	-	-	0.70	0.91	0.80	-	-	-	-

1/ Average coefficients determined by dividing sum of ET's by sum of E's.

(Salinas Valley, Vicinity of Soledad)

1963 – 1965

PASTURE

MONTH	EVAPOTRANSPIRATION (Inches)				PAN EVAPORATION (Inches)				NET ATMOMETER EVAPORATION (Milliliters)				PAN COEFFICIENTS ET/Ep				ATMOMETER COEFFICIENTS ET/Eb-w			
	1963	1964	1965	AVE	1963	1964	1965	AVE	1963	1964	1965	AVE	1963	1964	1965	AVE 1/	1963	1964	1965	AVE 1/
JAN	-	1.4	1.5	1.4	-	2.4	1.9	2.2	-	221	243	232	-	0.58	0.79	0.64	-	0.0063	0.0062	0.0060
FEB	-	2.6	2.3	2.4	-	3.8	3.5	3.6	-	265	300	288	-	0.68	0.66	0.67	-	0.0098	0.0077	0.0083
MAR	-	3.4	3.0	3.2	-	5.1	4.3	4.7	-	323	278	300	-	0.67	0.70	0.68	-	0.0105	0.0108	0.0107
APR	4.0	4.4	3.8	4.1	4.8	6.1	5.1	5.3	375	372	348	365	0.83	0.72	0.74	0.77	0.0107	0.0116	0.0109	0.0112
MAY	5.0	5.8	4.8	5.2	6.4	7.2	7.9	7.2	414	431	503	449	0.78	0.80	0.61	0.72	0.0121	0.0134	0.0095	0.0116
JUN	5.3	5.6	4.8	5.2	7.8	8.4	7.5	7.9	480	467	516	488	0.68	0.67	0.64	0.66	0.0110	0.0120	0.0093	0.0106
JUL	6.4	6.0	5.9	6.1	9.0	8.2	7.7	8.3	512	454	545	504	0.71	0.73	0.77	0.73	0.0125	0.0132	0.0108	0.0121
AUG	6.3	5.4	-	5.8	8.3	7.4	-	7.8	454	444	-	449	0.76	0.73	-	0.74	0.0139	0.0122	-	0.0129
SEP	4.8	5.3	-	5.0	7.0	7.4	-	7.2	422	372	-	397	0.68	0.72	-	0.69	0.0114	0.0142	-	0.0126
OCT	3.4	2.4	-	2.9	4.4	4.1	-	4.2	335	252	-	294	0.77	0.58	-	0.69	0.0101	0.0095	-	0.0099
NOV	2.0	2.1	-	2.0	2.5	2.4	-	2.4	237	242	-	240	0.80	0.88	-	0.83	0.0084	0.0087	-	0.0083
DEC	1.6	1.4	-	1.5	2.7	2.1	-	2.4	230	173	-	206	0.59	0.67	-	0.62	0.0070	0.0081	-	0.0073
ANNUAL	-	45.8	-	44.8	-	64.6	-	63.2	-	4016	-	4212	-	0.71	-	0.71	-	0.0114	-	0.0106

1/ Average coefficients determined by dividing sum of ET's by sum of E's.

(Big Valley Area – Glenburn)

1964 – 1965

PASTURE

MONTH	EVAPOTRANSPIRATION (Inches)			PAN EVAPORATION (Inches)			NET ATMOMETER EVAPORATION (Milliliters)			PAN COEFFICIENTS ET/Ep			ATMOMETER COEFFICIENTS ET/Eb-w		
	1964	1965	AVE	1964	1965	AVE	1964	1965	AVE	1964	1965	AVE 1/	1964	1965	AVE 1/
JAN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FEB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MAR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
APR	2.9	2.6	2.8	5.4	4.0	4.7	-	-	-	0.54	0.65	-	-	-	-
MAY	4.4	6.0	5.2	6.1	7.1	6.6	-	-	-	0.72	0.84	0.79	-	-	-
JUN	5.6	5.6	5.6	7.0	7.2	7.1	463	503	483	0.80	0.78	0.79	0.0121	0.0111	0.0116
JUL	6.6	6.9	6.8	10.0	8.7	9.4	526	587	557	0.66	0.79	0.72	0.0125	0.0118	0.0122
AUG	8.5	7.3	7.9	8.8	6.8	7.8	566	538	552	0.96	1.07	1.01	0.0150	0.0136	0.0143
SEP	5.1	4.9	5.0	5.8	5.1	5.4	462	384	423	0.88	0.96	0.92	0.0110	0.0128	0.0118
OCT	2.5	3.3	2.9	3.7	3.8	3.8	-	-	-	0.68	0.87	0.76	-	-	-
NOV	-	0.8	-	-	1.1	-	-	-	-	-	0.73	-	-	-	-
DEC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

1/ Average coefficients determined by dividing sum of ET's by sum of E's.

Table 8

MEADOW PASTURE

Monthly Summary

EVAPOTRANSPIRATION (ET), EVAPORATION (E), and ET/E RATIOS

(Alturas)

1959–1964

MONTH	EVAPOTRANSPIRATION (Inches)							PAN EVAPORATION (Inches)							PAN COEFFICIENTS ET/Ep						
	1959	1960	1961	1962	1963	1964	AVE	1959	1960	1961	1962	1963	1964	AVE	1959	1960	1961	1962	1963	1964	AVE[1/]
JAN	-	-	0.2	-	0.5	-	0.4	-	-	1.2	-	1.2	0.4	0.9	-	-	0.17	-	0.42	-	0.44
FEB	-	-	0.7	-	0.4	-	0.6	-	-	1.5	-	1.1	1.8	1.5	-	-	0.47	-	0.36	-	0.40
MAR	-	-	2.0	0.8	1.3	-	1.4	-	-	2.7	2.3	2.7	2.4	2.5	-	-	0.74	0.35	0.48	-	0.56
APR	5.2	3.0	4.7	4.4	1.6	2.4	3.6	5.5	4.5	6.0	6.1	2.7	4.3	4.8	0.94	0.67	0.78	0.72	0.59	0.56	0.75
MAY	6.0	4.8	6.6	4.8	3.5	3.9	4.9	6.1	5.9	6.6	6.3	5.7	5.9	6.1	0.98	0.81	1.00	0.76	0.61	0.66	0.80
JUN	9.0	6.6	8.3	7.4	5.7	5.0	7.0	7.9	8.0	8.3	8.6	5.8	5.8	7.4	1.14	0.82	1.00	0.86	0.98	0.86	0.94
JUL	10.4	9.6	10.2	8.6	7.3	8.1	9.0	9.8	8.8	8.6	9.0	9.0	8.7	9.0	1.06	1.09	1.19	0.96	0.81	0.93	1.00
AUG	9.0	9.3	7.3	8.4	7.6	8.5	8.4	8.6	8.3	7.6	8.6	8.5	8.6	8.4	1.05	1.12	0.96	0.98	0.89	0.99	1.00
SEP	4.9	6.0	6.6	5.9	4.7	5.0	5.5	5.5	5.9	5.9	6.2	5.3	5.6	5.7	0.96	1.02	1.12	0.95	0.89	0.89	0.96
OCT	2.8	3.6	3.0	2.3	3.0	3.1	2.9	3.6	3.7	3.1	3.0	3.6	3.6	3.4	0.78	0.97	1.00	0.77	0.83	0.86	0.85
NOV	-	-	-	1.1	-	-	-	-	-	-	1.6	1.0	0.7	1.1	-	-	-	0.69	-	-	0.69
DEC	-	0.8	-	0.6	-	-	0.7	-	0.6	-	1.0	0.6	0.4	0.6	-	1.33	-	0.60	-	-	0.88

MONTH	EVAPOTRANSPIRATION (Inches)							NET ATMOMETER EVAPORATION (Milliliters)							ATMOMETER COEFFICIENTS ET/Eb-w						
	1959	1960	1961	1962	1963	1964	AVE	1959	1960	1961	1962	1963	1964	AVE	1959	1960	1961	1962	1963	1964	AVE[1/]
JAN	-	-	0.2	-	0.5	-	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FEB	-	-	0.7	-	0.4	-	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MAR	-	-	2.0	0.8	1.3	-	1.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
APR	5.2	3.0	4.7	4.4	1.6	2.4	3.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MAY	6.0	4.8	6.6	4.8	3.5	3.9	4.9	-	-	-	418	406	400	408	-	-	-	0.0115	0.0086	0.0098	0.0120
JUN	9.0	6.6	8.3	7.4	5.7	5.0	7.0	547	562	575	597	478	571	555	0.0164	0.0117	0.0144	0.0124	0.0119	0.0088	0.0126
JUL	10.4	9.6	10.2	8.6	7.3	8.1	9.0	643	560	602	586	584	488	577	0.0162	0.0171	0.0169	0.0147	0.0125	0.0166	0.0156
AUG	9.0	9.3	7.3	8.4	7.6	8.5	8.4	551	501	491	552	540	419	509	0.0163	0.0186	0.0149	0.0152	0.0141	0.0203	0.0165
SEP	4.9	6.0	6.6	5.9	4.7	5.0	5.5	408	422	414	444	401	-	417	0.0120	0.0142	0.0159	0.0133	0.0117	-	0.0132
OCT	2.8	3.6	3.0	2.3	3.0	3.1	2.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NOV	-	-	-	1.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DEC	-	0.8	-	0.6	-	-	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(Lookout)

1961–1964

MONTH	EVAPOTRANSPIRATION (Inches)							PAN EVAPORATION (Inches)							PAN COEFFICIENTS ET/Ep						
	1959	1960	1961	1962	1963	1964	AVE	1959	1960	1961	1962	1963	1964	AVE	1959	1960	1961	1962	1963	1964	AVE[1/]
JAN	-	-	0.2	-	-	-	-	-	-	1.0	-	-	-	-	-	-	0.20	-	-	-	-
FEB	-	-	0.3	-	-	-	-	-	-	1.0	-	-	-	-	-	-	0.30	-	-	-	-
MAR	-	-	1.0	-	1.4	-	1.2	-	-	2.4	-	2.3	-	2.4	-	-	0.42	-	0.61	-	0.50
APR	-	-	3.8	3.8	-	-	3.8	-	-	5.6	5.5	-	-	5.6	-	-	0.68	0.69	-	-	0.68
MAY	-	-	5.1	5.5	-	-	5.3	-	-	6.2	5.8	-	-	6.0	-	-	0.82	0.95	-	-	0.88
JUN	-	-	7.8	7.1	6.4	-	7.1	-	-	7.8	8.5	6.8	-	7.7	-	-	1.00	0.84	0.94	-	0.92
JUL	-	-	9.0	8.5	9.5	-	9.0	-	-	10.7	9.8	9.0	-	9.8	-	-	0.84	0.87	1.06	-	0.92
AUG	-	-	7.4	8.0	8.7	-	8.0	-	-	7.6	9.7	8.8	-	8.7	-	-	0.97	0.82	0.99	-	0.92
SEP	-	-	6.0	5.8	4.8	-	5.5	-	-	6.4	6.8	4.8	-	6.0	-	-	0.94	0.85	1.00	-	0.92
OCT	-	-	3.0	2.3	3.8	-	3.0	-	-	3.9	3.3	3.3	-	3.5	-	-	0.77	0.70	1.15	-	0.86
NOV	-	-	-	1.0	-	-	-	-	-	-	1.6	-	-	-	-	-	-	0.62	-	-	-
DEC	-	-	-	0.5	-	-	-	-	-	-	0.9	-	-	-	-	-	-	0.56	-	-	-

MONTH	EVAPOTRANSPIRATION (Inches)							NET ATMOMETER EVAPORATION (Milliliters)							ATMOMETER COEFFICIENTS ET/Eb-w						
	1959	1960	1961	1962	1963	1964	AVE	1959	1960	1961	1962	1963	1964	AVE	1959	1960	1961	1962	1963	1964	AVE[1/]
JAN	-	-	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FEB	-	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MAR	-	-	1.0	-	1.4	-	1.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
APR	-	-	3.8	3.8	-	-	3.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MAY	-	-	5.1	5.5	-	-	5.3	-	-	-	390	-	-	-	-	-	-	0.0141	-	-	0.0141
JUN	-	-	7.8	7.1	6.4	-	7.1	-	-	564	568	509	-	547	-	-	0.0138	0.0125	0.0126	-	0.0130
JUL	-	-	9.0	8.5	9.5	-	9.0	-	-	578	568	619	-	588	-	-	0.0156	0.0150	0.0153	-	0.0153
AUG	-	-	7.4	8.0	8.7	-	8.0	-	-	478	504	539	-	507	-	-	0.0155	0.0159	0.0161	-	0.0158
SEP	-	-	6.0	5.8	4.8	-	5.5	-	-	404	407	406	-	406	-	-	0.0148	0.0143	0.0118	-	0.0135
OCT	-	-	3.0	2.3	3.8	-	3.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NOV	-	-	-	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DEC	-	-	-	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

1/ Average coefficients determined by dividing sum of ET's by sum of E's.

Table 9

ALFALFA

Monthly Summary

EVAPOTRANSPIRATION (ET), EVAPORATION (E), and ET/E RATIOS

(Bakersfield Area)

1959, 1960, 1963

MONTH	EVAPOTRANSPIRATION (Inches)				PAN EVAPORATION (Inches)				NET ATMOMETER EVAPORATION (Milliliters)				PAN COEFFICIENTS ET/E_p				ATMOMETER COEFFICIENTS ET/Eb-w			
	1959	1960	1963	AVE	1959	1960	1963	AVE	1959	1960	1963	AVE	1959	1960	1963	AVE 1/	1959	1960	1963	AVE 1/
JAN	-	-	1.8	1.8	-	-	1.8	-	-	-	-	-	-	-	1.00	-	-	-	-	-
FEB	-	-	2.1	2.1	-	-	2.4	-	-	-	-	-	-	-	0.88	-	-	-	-	-
MAR	-	-	3.9	3.9	-	-	5.4	-	-	-	365	-	-	-	0.72	-	-	-	0.0107	-
APR	4.5	-	3.8	4.2	7.0	-	5.2	6.1	473	-	355	414	0.64	-	0.73	0.69	0.0095	-	0.0108	0.0101
MAY	4.5	-	6.3	5.4	8.7	-	8.1	8.4	498	-	437	468	0.52	-	0.78	0.64	0.0090	-	0.0144	0.0115
JUN	5.8	7.7	7.0	6.8	9.1	10.0	9.6	9.6	571	670	475	572	0.64	0.77	0.73	0.71	0.0102	0.0115	0.0147	0.0119
JUL	6.3	6.0	8.3	6.9	10.0	9.4	9.7	9.7	582	639	562	594	0.63	0.64	0.86	0.71	0.0108	0.0094	0.0148	0.0116
AUG	6.1	6.6	7.0	6.6	8.7	8.1	7.8	8.2	548	582	551	560	0.70	0.81	0.90	0.80	0.0111	0.0113	0.0127	0.0118
SEP	5.3	4.1	4.7	4.7	5.9	6.1	5.5	5.8	473	480	465	473	0.90	0.67	0.85	0.81	0.0112	0.0085	0.0101	0.0099
OCT	3.2	2.6	3.1	3.0	4.5	4.1	3.4	4.0	413	372	340	375	0.71	0.63	0.91	0.75	0.0077	0.0070	0.0091	0.0080
NOV	2.8	-	1.4	2.1	2.7	-	2.0	2.4	-	-	-	-	1.04	-	0.70	0.88	-	-	-	-
DEC	1.9	-	0.8	1.4	1.7	-	0.8	1.2	-	-	-	-	1.12	-	1.00	1.17	-	-	-	-
Mar-Oct 2/			44.1	41.5			54.7				3550				0.81				0.0124	
ANNUAL			50.2	48.9			61.7				-				0.81				-	

1/ Average coefficients determined by dividing sum of ET's by sum of E's.

2/ Growing Season

(Near Pittville)

1959-1962

MONTH	EVAPOTRANSPIRATION (Inches)					PAN EVAPORATION (Inches)					NET ATMOMETER EVAPORATION (Milliliters)					PAN COEFFICIENTS ET/Ep					ATMOMETER COEFFICIENTS ET/Eb-w				
	1959	1960	1961	1962	AVE	1959	1960	1961	1962	AVE	1959	1960	1961	1962	AVE	1959	1960	1961	1962	AVE 1/	1959	1960	1961	1962	AVE 1/
JAN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FEB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MAR	-	-	0.8	-	-	-	-	2.8	-	-	-	-	-	-	-	-	-	0.28	-	-	-	-	-	-	-
APR	-	2.8	4.4	4.6	3.9	-	4.6	5.3	6.2	5.4	-	-	-	-	-	-	0.61	0.83	0.74	0.72	-	-	-	-	-
MAY	6.8	6.4	5.4	6.0	6.2	-	6.7	6.2	6.5	6.5	626	-	468	432	509	-	0.96	0.87	0.92	0.95	0.0109	-	0.0115	0.0139	0.0122
JUN	6.9	5.6	6.5	6.7	6.4	-	8.7	8.4	9.3	8.8	606	586	614	566	592	-	0.64	0.77	0.72	0.73	0.0114	0.0096	0.0106	0.0118	0.0108
JUL	9.0	8.4	-	6.4	7.9	-	10.4	-	10.5	10.4	659	583	-	660	634	-	0.81	-	0.61	0.76	0.0136	0.0144	-	0.0097	0.0125
AUG	6.2	8.9	6.6	5.5	6.8	-	9.2	7.7	9.0	8.6	646	552	482	531	552	-	0.97	0.86	0.61	0.79	0.0096	0.0161	0.0137	0.0104	0.0123
SEP	6.9	5.1	5.1	7.0	6.0	-	5.9	6.0	6.6	6.2	481	451	441	437	452	-	0.86	0.85	1.06	0.97	0.0143	0.0113	0.0116	0.0160	0.0133
OCT	-	3.8	2.1	-	3.0	-	4.0	4.1	-	4.0	-	-	-	-	-	-	0.95	0.51	-	0.75	-	-	-	-	-
NOV	-	-	0.5	-	-	-	-	1.5	-	-	-	-	-	-	-	-	-	0.33	-	-	-	-	-	-	-
DEC	-	-	0.1	-	-	-	-	0.7	-	-	-	-	-	-	-	-	-	0.14	-	-	-	-	-	-	-
MAY-SEPT	35.8	34.4	-	31.6	33.3	-	40.90	-	41.9	40.5	3018	-	-	2626	2729	-	0.84	-	0.75	0.82	0.0119	-	-	0.0120	0.0122
APR-OCT 2/	-	41.0	-	-	40.2	-	49.5	-	-	49.9						-	0.83	-	-	0.81					

1/ Average coefficients determined by dividing sum of ET's by sum of E's.

2/ Growing season.

flow meter. The application of irrigation water was controlled so that no deep percolation or runoff occurred. This provided just enough water for the crop and no more. The amount of irrigation water applied to the plot was based upon soil suction data from tensiometers installed at 1-foot increments to a depth of 10 feet. Because of the low rainfall in the area, all precipitation was utilized as evapotranspiration.

The tensiometer records indicated that no soil moisture was drained to depths below the crop root zone. While the actual change in soil moisture storage is unknown, general indications are that soil moisture tended to decrease during the two-year period. Therefore, the total of measured applied water plus precipitation, 47 inches per year for both years, indicates that evapotranspiration was at least 47 inches and probably a little more. This annual amount compares favorably to the 48 inches determined earlier in the soil moisture depletion plots.

Cotton - The cultural practices followed in cotton production are variable because of the different planting methods used. Cotton is commonly planted in rows spaced 38 inches apart, but, because of crop allotment controls, other spacings have become popular. In "solid" cotton, each row is planted; in "skip row" cotton some of the 38-inch-spaced rows are left unplanted.

The evapotranspiration rate of solid cotton was measured by the neutron scattering technique during 1959, 1960, and 1961. In 1962, a 2x2 skip row planting (2 rows planted, 2 rows unplanted) was sampled and the evapotranspiration found to be about 15 percent lower than for solid cotton, as explained below. Skip row 2x1 cotton (2 rows planted, 1 row unplanted) measured during the 1963 year had about the same evapotranspiration coefficients as solid plantings measured in earlier years. These results, along with evaporation data and ET/E ratios, are presented in Table 10.

The relationship between pan coefficient and percent ground cover for 3 cultural treatments is shown in Figure 10. This figure shows ET/Ep ratios and ground cover conditions which are approximately the same for all cultural treatments in the early part of the growing season. As the crop develops, the ET/Ep ratios for the skip row cotton exceed the ET/Ep ratio for the solid planting. This is probably due in part to increased turbulent mixing of the air above the crop caused by the rougher surface of the skip row cotton and in part to internal advection from the bare soil in the skip rows. In August, after the crop has reached maturity and attained maximum ground cover, the ET/Ep ratios for all three cultural treatments decrease. This is due to the physiological effects of plant aging which decrease evapotranspiration rates from those observed when the plants were younger and more vigorous, even at the same percentage of cover.

Table 10
COTTON
Monthly Summary
EVAPOTRANSPIRATION (ET), EVAPORATION (E), and ET/E RATIOS

(Bakersfield Area)

1959 — 1963 1/

MONTH	EVAPOTRANSPIRATION (Inches)							PAN EVAPORATION 2/ (Inches)							PAN COEFFICIENTS ET/Ep						
	1959	1960	1961	AVE 59-61	1962	1963	AVE ALL YRS	1959	1960	1961	AVE 59-61	1962	1963	AVE ALL YRS	1959	1960	1961	AVE 59-61	1962	1963	AVE 3/ ALL YRS
JAN	-	-	0.4	-	0.6	0.1	0.4	-	-	0.9	-	1.6	1.8	1.4	-	-	0.44	-	0.38	0.06	0.28
FEB	-	-	1.4	-	0.6	0.8	0.9	-	-	2.6	-	1.9	2.4	2.3	-	-	0.54	-	0.32	0.33	0.39
MAR	-	1.1	1.1	1.1	1.0	1.2	1.1	-	4.3	3.9	4.1	4.3	5.4	4.5	-	0.26	0.28	0.27	0.23	0.22	0.24
APR	-	0.8	0.4	0.6	1.1	1.5	1.0	-	5.8	6.6	6.2	7.6	5.3	6.3	-	0.14	0.06	0.10	0.14	0.28	0.16
MAY	1.6	0.3	1.1	1.0	0.7	1.6	1.1	8.6	8.7	7.6	8.3	8.6	8.1	8.3	0.19	0.03	0.14	0.13	0.08	0.20	0.13
JUN	7.5	5.3	5.5	6.1	3.9	4.7	5.4	9.3	10.0	9.9	9.7	10.5	9.6	9.9	0.81	0.53	0.55	0.63	0.37	0.49	0.54
JUL	10.7	10.1	8.6	9.8	9.1	8.8	9.5	9.8	9.4	9.6	9.6	10.4	9.7	9.8	1.09	1.07	0.90	1.02	0.88	0.91	0.97
AUG	7.8	8.9	8.2	8.3	7.9	8.3	8.2	8.6	8.1	7.8	8.2	8.6	7.8	8.2	0.91	1.10	1.05	1.01	0.92	1.06	1.00
SEP	5.1	5.0	5.7	5.3	5.0	4.8	5.1	5.9	6.1	6.2	6.1	6.0	5.5	5.9	0.86	0.82	0.92	0.87	0.83	0.87	0.86
OCT	3.0	1.0	2.4	2.1	1.6	2.6	2.1	4.4	4.1	4.4	4.3	3.9	3.4	4.0	0.68	0.24	0.54	0.49	0.41	0.76	0.52
NOV	0.2	1.0	0.7	0.6	0.3	0.4	0.5	2.6	1.9	2.4	2.3	2.2	2.0	2.2	0.08	0.53	0.29	0.26	0.14	0.20	0.23
DEC	-	0.4	0.4	0.4	-	0.2	0.3	-	1.1	1.2	1.2	-	0.8	1.0	-	0.36	0.33	0.33	-	0.25	0.30
MAY-OCT 4/	35.7	30.6	31.5	32.6	28.2	30.8	31.4	46.6	46.4	45.5	46.2	48.0	44.1	46.1	0.77	0.66	0.69	0.70	0.59	0.70	0.68
ANNUAL	-	-	35.9	-	-	35.0	35.6	-	-	63.1	-	66.4	60.8	63.2	-	-	0.57	-	0.48	0.58	0.56

MONTH	EVAPOTRANSPIRATION (Inches)							NET ATMOMETER EVAPORATION 2/ (Milliliters)							ATMOMETER COEFFICIENTS ET/Eb-w						
	1959	1960	1961	AVE 59-61	1962	1963	AVE ALL YRS	1959	1960	1961	AVE 59-61	1962	1963	AVE ALL YRS	1959	1960	1961	AVE 59-61	1962	1963	AVE ALL YRS 3/
JAN	-	-	0.4	-	0.6	0.1	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FEB	-	-	1.4	-	0.6	0.8	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MAR	-	1.1	1.1	1.1	1.0	1.2	1.1	-	-	364	-	344	365	358	-	-	0.0030	-	0.0029	0.0033	0.0031
APR	-	0.8	0.4	0.6	1.1	1.5	1.0	-	438	475	456	444	355	428	-	0.0018	0.0008	0.0013	0.0025	0.0042	0.0023
MAY	1.6	0.3	1.1	1.0	0.7	1.6	1.1	498	570	504	524	500	437	502	0.0032	0.0005	0.0022	0.0019	0.0014	0.0037	0.0022
JUN	7.5	5.3	5.5	6.1	3.9	4.7	5.4	571	670	610	617	601	475	585	0.0131	0.0079	0.0090	0.0099	0.0065	0.0099	0.0092
JUL	10.7	10.1	8.6	9.8	9.1	8.8	9.5	582	639	610	610	622	562	603	0.0184	0.0158	0.0141	0.0161	0.0146	0.0156	0.0158
AUG	7.8	8.9	8.2	8.3	7.9	8.3	8.2	548	582	529	553	576	551	557	0.0142	0.0153	0.0155	0.0150	0.0137	0.0151	0.0147
SEP	5.1	5.0	5.7	5.3	5.0	4.8	5.1	473	480	485	479	498	465	480	0.0108	0.0104	0.0118	0.0111	0.0100	0.0103	0.0106
OCT	3.0	1.0	2.4	2.1	1.6	2.6	2.1	413	372	350	378	355	340	366	0.0073	0.0027	0.0068	0.0056	0.0045	0.0076	0.0057
NOV	0.2	1.0	0.7	0.6	0.3	0.4	0.5	293	223	-	258	244	240	250	0.0007	0.0045	-	0.0023	0.0012	0.0017	0.0020
DEC	-	0.4	0.4	0.4	-	0.2	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MAY-OCT 4/	35.7	30.6	31.5	32.6	28.2	30.8	31.4	3085	3313	3088	3161	3152	2830	3093	0.0116	0.0092	0.0102	0.0103	0.0089	0.0109	0.0102
ANNUAL	-	-	35.9	-	-	35.0	35.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-

1/ 1959, 1960, 1961 - Solid plant cotton
1962 - Skip row cotton, 2x2
1963 - Skip row cotton, 2x1

2/ Pan and net atmometer evaporation measured in grass environment.

3/ Average coefficients determined by dividing sum of ET's by E's.

4/ Growing season.

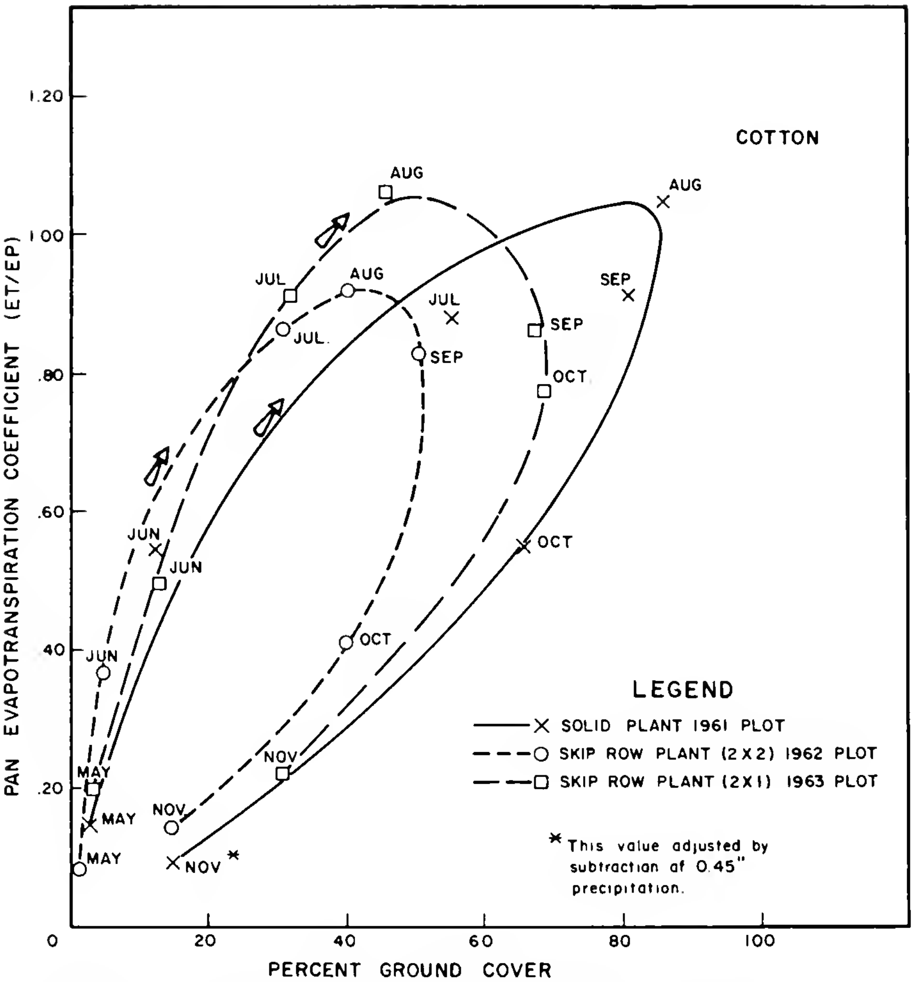


Figure 10. RELATIONSHIP BETWEEN PAN EVAPOTRANSPIRATION COEFFICIENT AND PERCENT GROUND COVER FOR COTTON

The bulk of the cotton in the San Joaquin Valley is planted in early April and defoliated between September and the middle of October. The evapotranspiration rate following plant emergence in April is quite low. The most active rate of evapotranspiration begins about May 1 and increases rapidly during the growing season. Following defoliation, the rate quickly drops off. The greatest amount of growing season evapotranspiration occurs between May 1 and October 15.

For broad planning, average monthly coefficients based upon the three cultural treatments give satisfactory results. However, for more detailed planning, operation, and hydrology studies, where the cultural treatments are known or can be predicted, it is recommended that the cotton acreage be broken down by cultural practice and appropriate coefficients used. The solid-planted and 2x1 skip row can, because of the similarity in evapotranspiration rates, be placed in one

group and the 2x2 skip row placed in another. These data are presented in sufficient detail to permit adjustments for differences in length of growing season.

Deciduous Orchards (Plums) - Evapotranspiration rates, using the neutron scattering technique, were determined within a large, clean-cultivated, well-managed planting of mature Santa Rosa plums near Bakersfield in the southern San Joaquin Valley. The orchard was furrow-irrigated in such a manner that a strip, about 6 feet wide, was left unirrigated down each tree row. This is a typical irrigation practice in deciduous orchards. Data collected at this plot during part or all of the period 1959-64 are presented in Table 11.

Although a perennial crop, plums (and other deciduous trees) are similar to annual crops in development of transpiring vegetation. From essentially a bare condition during the winter, the trees in the sampled plot began leafing out during the first part of March, attained a maximum vegetative cover of 45 percent approximately one month later, and maintained this maximum cover fairly constantly until late October, when the leaves began to drop. Complete defoliation usually occurred by mid-November.

Starting in December and continuing until March, evapotranspiration from the plum orchard consisted almost entirely of evaporation from a moist soil surface, wetted by precipitation and winter irrigation. After this date, however, the transpirational component of evapotranspiration took on prime importance as the ground cover rapidly increased. In contrast to cotton, the ET/E ratios of orchards continued to increase for some time after the maximum ground cover was attained. This was probably due to the combined effects of advection, surface roughness, and plant physiology.

The data also shows that the ET/E ratios of plums reach values nearly as high as those for pasture at mid-season, even though their ground cover was only about half that of pasture. Some influence of plant physiology is indicated with the dropping off of the ET/E ratios in August or September even though the percentage of ground cover remained unchanged until October.

The effects of soil moisture stress on evapotranspiration rates were demonstrated during the late summer of 1962. When the soil moisture content approached near the permanent wilting percentage, a marked decrease in ET/E ratios was observed. Following irrigation, the ratios increased to a normal level. No leaf drop was observed during the period of moisture stress.

Deciduous orchards in the San Joaquin Valley commonly receive a deep wintertime (nongrowing season) irrigation. This stored

Table II

PLUMS

Monthly Summary

EVAPOTRANSPIRATION (ET), EVAPORATION (E), and ET/E RATIOS

(Bakersfield Area)

1959 – 1964

MONTH	MEASURED EVAPOTRANSPIRATION (Inches)						PAN EVAPORATION[1] (Inches)						NET ATMOMETER EVAPORATION[1] (Milliliters)						PAN COEFFICIENTS ET/Ep						ATMOMETER COEFFICIENTS ET/Eb-w					
	1959	1960	1962	1963	1964	AVE	1959	1960	1962	1963	1964	AVE	1959	1960	1962	1963	1964	AVE	1959	1960	1962	1963	1964	AVE[2]	1959	1960	1962	1963	1964	AVE[2]
JAN	-	-	0.6	0.7	0.8	0.7	-	-	1.6	1.8	1.5	1.6	-	-	-	-	-	-	-	-	0.38	0.39	0.53	0.44	-	-	-	-	-	-
FEB	-	-	1.3	1.7	1.1	1.4	-	-	1.9	2.4	3.3	2.5	-	-	-	-	-	-	-	-	0.68	0.71	0.33	0.56	-	-	-	-	-	-
MAR	-	-	1.1	3.0	-	2.0	-	-	4.3	5.4	-	4.8	-	-	344	365	-	355	-	-	0.26	0.56	-	0.42	-	-	0.0032	0.0082	-	0.0056
APR	3.6	-	2.7	4.8	-	3.7	7.1	-	7.6	5.2	-	6.6	473	-	444	355	-	424	0.51	-	0.36	0.92	-	0.56	0.0076	-	0.0061	0.0135	-	0.0087
MAY	6.0	-	5.1	5.4	-	5.5	8.6	-	8.6	8.1	-	8.4	498	-	500	437	-	478	0.70	-	0.59	0.67	-	0.65	0.0120	-	0.0102	0.0124	-	0.0115
JUN	6.4	8.2	6.5	5.9	5.6	6.5	9.3	10.0	10.5	9.6	9.8	9.8	571	670	601	475	525	568	0.69	0.82	0.62	0.61	0.57	0.66	0.0112	0.0122	0.0108	0.0124	0.0107	0.0114
JUL	8.1	8.7	6.9	6.7	7.6	7.6	9.8	9.4	10.4	9.7	9.2	9.7	582	639	622	562	545	590	0.83	0.92	0.66	0.69	0.83	0.78	0.0139	0.0136	0.0111	0.0119	0.0139	0.0129
AUG	6.5	6.4	4.1[3]	7.0	7.0	6.2 (6.7)	8.6	8.1	8.6	7.8	8.1	8.2	548	582	576	551	531	558	0.76	0.79	0.48	0.90	0.86	0.76	0.0119	0.0110	0.0071	0.0127	0.0132	0.0111
SEP	2.5	4.7	4.1[3]	5.2	5.7	4.4 (4.5)	5.9	6.1	6.0	5.5	6.0	5.9	473	480	498	465	470	477	0.42	0.77	0.68	0.94	0.95	0.74	0.0053	0.0098	0.0082	0.0112	0.0121	0.0092
OCT	1.0[3]	1.4	3.4	2.8	3.8	2.5 (2.8)	4.4	4.1	3.9	3.4	4.3	4.0	413	372	355	340	376	371	0.23	0.34	0.87	0.82	0.88	0.62	0.0024	0.0038	0.0096	0.0082	0.0101	0.0067
NOV	0.1[3]	0.4	2.0	1.6	0.6	0.9 (1.2)	2.6	1.9	2.2	2.0	1.9	2.1	293	223	244	240	300	260	0.04	0.21	0.91	0.84	0.32	0.43	0.0003	0.0018	0.0082	0.0067	0.0030	0.0035
DEC	-	-	0.6	0.3	0.9	0.6	-	-	1.8	0.8	1.5	1.4	-	-	-	-	-	-	-	-	0.33	0.38	0.60	0.43	-	-	-	-	-	-
MAR-NOV Total[4]			35.9	42.4	-	39.3 (40.5)	-	-	62.1	56.7	-	59.5	-	-	4144	3790	-	4081	-	-	0.58	0.75	-	0.66 (0.68)	-	-	0.0087	0.0112	-	0.0096 (0.0099)
ANNUAL			38.4	45.1	-	42.0 (43.2)	-	-	67.4	61.7	-	65.0	-	-	-	-	-	-	-	-	0.57	0.73	-	0.65 (0.66)	-	-	-	-	-	-

1/ Pan and net atmometer evaporation measured in grass environment.

2/ Average coefficients determined by dividing sum of ET's by sum of E's.

3/ Suspected effect of soil moisture stress.

4/ Growing Season.

() Estimated values (calculated by not including ET in month where soil moisture stress was suspected).

moisture is evapotranspired during the growing season. Figure 11 shows decrease in stored soil moisture which occurred during the growing season. This figure was based upon observations made at the Bakersfield plum plot. It shows that the amount of water applied during the growing season was insufficient to meet the evapotranspiration demand of the trees. Only by use of the stored moisture was this evapotranspiration demand met.

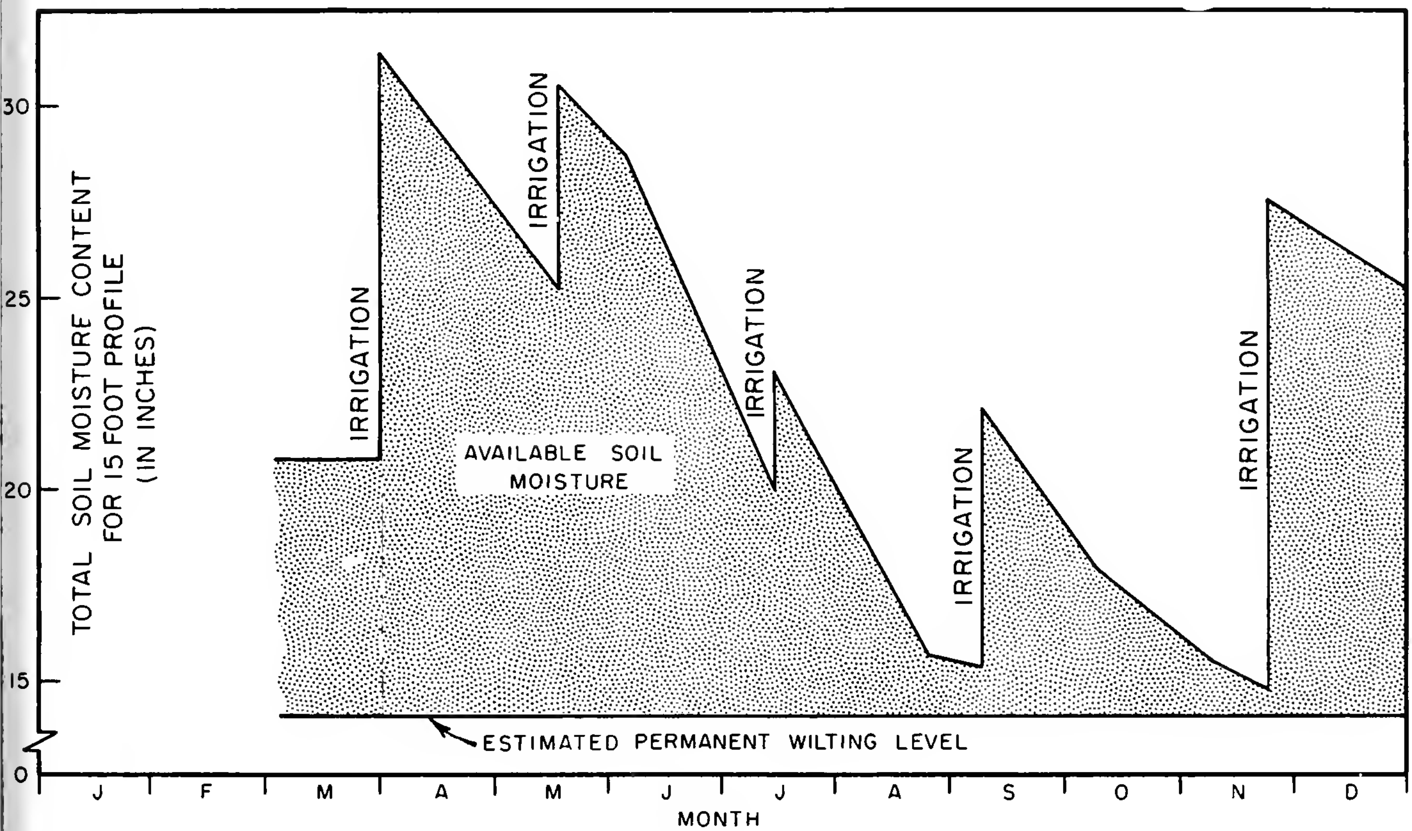


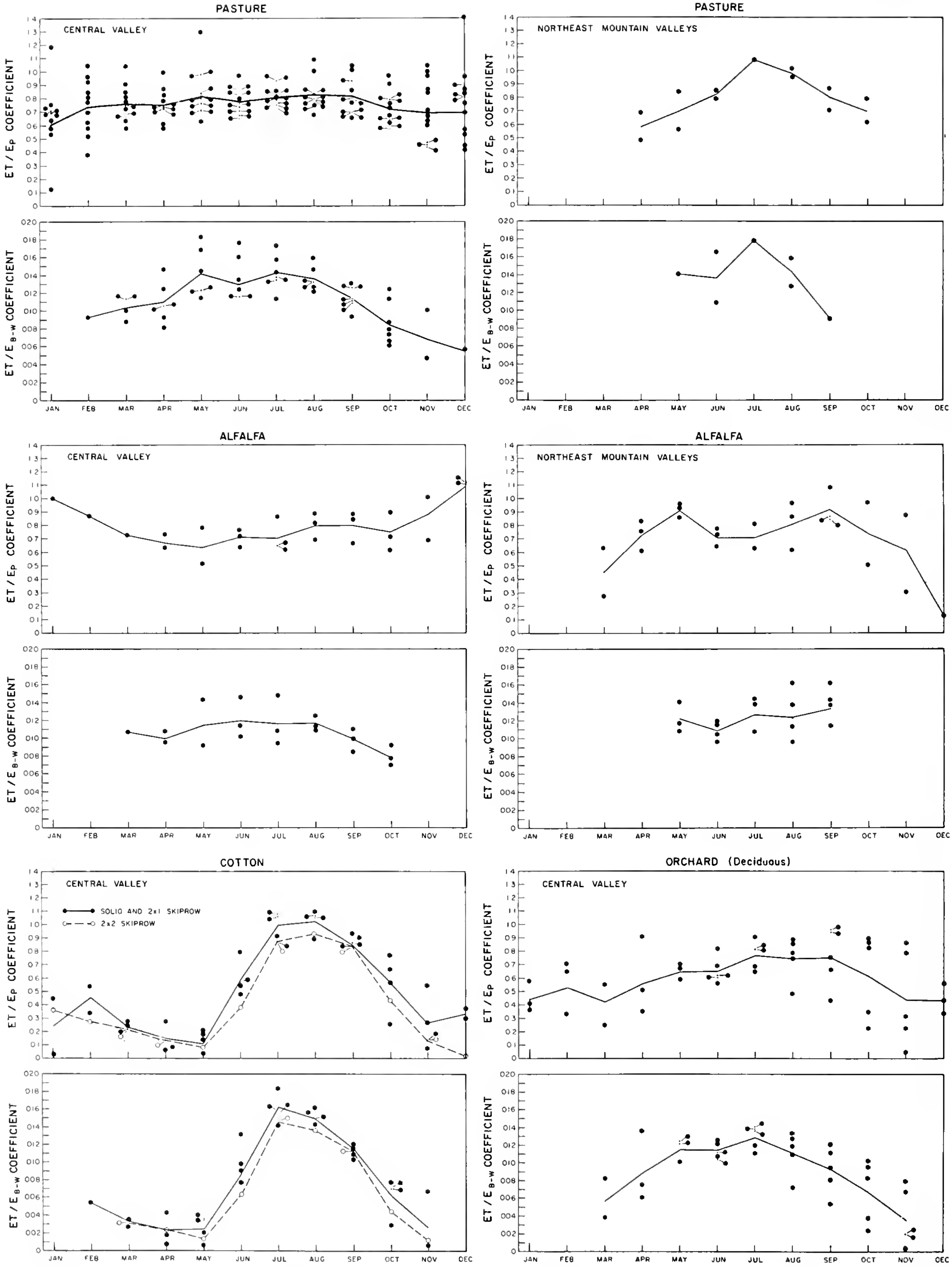
Figure 11. USE OF STORED SOIL MOISTURE BY PLUMS

Average Monthly Pan and Atmometer Evapotranspiration Coefficients

Figure 12 shows computed individual monthly evapotranspiration coefficients plotted for several crops studied in the Central Valley and northeastern mountain valleys. Lines connecting monthly arithmetic averages also are shown.

There are many factors which affect the individual monthly coefficients. The average coefficient for a crop having fairly uniform ground cover, such as pasture, is reasonably constant. The effect of changing ground cover conditions

FIGURE 12



ET/E_P AND $ET/E_{B\text{-}W}$ RATIOS FROM MEASURED DATA FOR SEVERAL IRRIGATED CROPS

and physiological factors associated with crop maturity are shown by the cotton data. Some of the variability in the orchard data is believed to be related to soil moisture availability.

In the following chapters the data presented in this chapter are used to develop recommended evapotranspiration coefficients to estimate monthly evapotranspiration of applied water values.

CHAPTER IV. ESTIMATING EVAPOTRANSPIRATION

It is not practical to measure actual evapotranspiration rates of native vegetation and all the important agricultural crops. For this reason, methods have been developed for obtaining evapotranspiration values that will approximate actual values. For native vegetation and nonirrigated crops, the method is based upon a moisture budget in which potential evapotranspiration and precipitation are the prime items considered. In the case of irrigated crops, the method is to correlate evapotranspiration measurements of a few crops to evaporative demand measurements made at the same locations, and use the resulting relationship to estimate monthly and annual evapotranspiration for these and other crops throughout the State. This chapter presents methods for estimating these values and for separating them into evapotranspiration of applied water and evapotranspiration of precipitation.

Estimating Evapotranspiration of Nonirrigated Lands

In order to estimate evapotranspiration of an entire watershed, and to determine differences of water use resulting from changing land use, estimates of evapotranspiration rates of nonirrigated lands need to be made.

There are several factors that govern monthly and annual evapotranspiration from nonirrigated lands. If no restrictions on the availability of water exist, evaporative demand is the controlling factor. Potential evapotranspiration, discussed in Chapter III, provides a good estimate of the approximate upper limit of actual evapotranspiration for this condition. Where the availability of water is limited, however, other factors may influence evapotranspiration rates. An extremely important factor is the amount and frequency of precipitation, the main source of water. Soil characteristics are also important. The soil infiltration rate, soil moisture holding capacity, and depth of plant rooting affect the amount of water that can be stored and carried over from the period when the rainfall exceeds the rate of evapotranspiration. Percent ground cover, crop roughness, and the growing season of the plants are also factors affecting the actual evapotranspiration rate.

The procedure recommended for estimating evapotranspiration of nonirrigated crops and native vegetation is to first make estimates of potential evapotranspiration, plant rooting depth, soil moisture holding capacity, growing season, and ground cover conditions. Precipitation records representative of the study area are then used to estimate the amount of water temporarily stored in the soil, and later utilized by the vegetation.

This information is arranged in a manner that shows evapotranspiration of direct and stored precipitation for each month. This budget-keeping procedure is demonstrated in Table 12 for a nonirrigated barley crop in the Sacramento Valley.

Estimating Evapotranspiration of Irrigated Crops

Among the principle crops in the Central Valley are pasture, alfalfa, cotton, deciduous orchards, sugar beets and rice. These crops represent approximately 65 percent of the total 1960 irrigated acreage in the Central Valley and approximately 61 percent of the projected acreage for the year 2015. Except for rice, actual field measurements of evapotranspiration have been obtained for these crops.

Growing Season Evapotranspiration

Recommended coefficients relating evapotranspiration of these crops to evaporation from pans and atmometers were developed to estimate growing season evapotranspiration. For this purpose data were collected by the Department and made available by the University of California at Davis.

Coefficients have been developed only for the Central Valley. They may be used, however, with judgment for the same or other crops in all climatic and geographic regions of the State. When used for this purpose, information on dates of planting, emergence and harvest; development of ground cover percentage, and crop surface roughness must be considered for the crop. Table 13 is an example of the types of data considered in developing recommended coefficients.

Grass and Pasture - Irrigated grass and pasture has essentially a 100 percent ground cover, is low growing, and has a fairly smooth surface. As a generalization, the evapotranspiration rate of irrigated improved pasture may be considered to be near the upper limit for most crops. However, as shown in Chapter III, some crops do have higher evapotranspiration rates than pasture during certain stages of their growth.

Recommended coefficients for pasture were based upon approximately one and one-half years of pan, atmometer and evapotranspiration data collected by the Department near Thornton, four full years of similar data collected by the Department near Bakersfield, and five and one-half years of pan and evapotranspiration data collected by the University of California at Davis. These data are shown on Table 7. Monthly ET/E ratios were computed from evapotranspiration tion data and from evaporation data collected near each evapotranspiration site. Monthly ET/E ratios and arithmetic means of the values have been plotted in Figure 12.

Table 12
NON-IRRIGATED BARLEY EVAPOTRANSPIRATION
SACRAMENTO VALLEY
(in inches)

Assumptions:

Average planting date - 12/1
Average emergency date - 12/10
Maximum ground cover attained - 4/1

Harvest data - 6/1
Available water per foot - 1.5"/ft.
Root Zone - 4'
Total available water - 6"

Month	Precip.	PET 1/	Direct ET of Precip.	Precip. into Storage 2/	ET of Stored Precip.	Precip. Avail. in Storage	Deep Percolation	Estimated ET
OCT.	2.0	3.5	2.0	0.0	0.0	0.0	0.0	2.0
NOV.	5.4	1.6	1.6	3.8	0.0	3.8	0.0	1.6
DEC.	0.3	0.8	0.3	0.0	0.5	3.3	0.0	0.8
JAN.	4.6	1.0	1.0	2.7	0.0	6.0	0.9	1.0
FEB.	0.4	1.8	0.4	0.0	1.4	4.6	0.0	1.8
MAR.	1.7	3.0	1.7	0.0	1.3	3.3	0.0	3.0
APR.	0.2	4.7	0.2	0.0	3.3	0.0	0.0	3.5
MAY	1.3	6.1	1.3	0.0	0.0	0.0	0.0	1.3
JUN.	0.4	7.8	0.4	0.0	0.0	0.0	0.0	0.4
JUL.	0.0	8.2	0.0	0.0	0.0	0.0	0.0	0.0
AUG.	0.0	7.1	0.0	0.0	0.0	0.0	0.0	0.0
SEP.	0.3	5.2	0.3	0.0	0.0	0.0	0.0	0.3
Total	16.6	50.8	9.2	6.5	6.5	-	0.9	15.7

1/ From Table 16, "Tentative Recommended Monthly Evapotranspiration Values for Some Principal Central Valley Crops".

2/ The amount into storage for a particular month plus the amount of precipitation available in storage for the previous month cannot exceed 6".

Table 13

GROWING SEASONS AND CULTURAL PRACTICES

For Several Irrigated Crops in Southern San Joaquin Valley

Crop	CROP DEVELOPMENT: Planting Date range	Planting Date average	Harvest first/last date range	Harvest first/last date average	Harvest yield range	Harvest yield average	Ground Cover emergence date average	Ground Cover max. growth date average	Ground Cover harvest or defoliation date begin average	Ground Cover harvest or defoliation date end average	+/- variation from each average (days)	Usual Method	IRRIGATION PRACTICE: Pre-irrigation date	Pre-irrigation range Ac Ft/Ac	Pre-irrigation average Ac Ft/Ac	Growing Season Irrigations first/last date range	Growing Season Irrigations first/last date average	no. of irri. range	no. of irri. average	Total Applied (Ac Ft/Ac) range	Total Applied (Ac Ft/Ac) average
ALFALFA																					
Hay	- - -a/	- - -a/	4-1-10/15 b/	30 day inter	6-8 tn/ac c/	8 tn/ac	2/1	every 30 days from 4/1-12/1	4/1	12/1 b/	- - -	border	12/1-2/1	0.5 1.0	1.0	2/15-10/1	3/1-10/1	every 10-14 days	every 2 wks	4.0-6.0	5.0
Seed	- - -a/	- - -a/	4/1 d/	4/1 d/	[illegible]00-700 lb/ac e/	around 300 lb/ac e/	2/1	4/1 (cut 6/1)	8/1	9/1	20	furrow	12/1-2/1	0.5 1.0	1.0	3/1-8/1	- - -	1-4 days	3 "	2.0-3.5	2.5
BEANS																					
Blackeyes, 1st crop	4/15-6/20	5/10	9/16-9/26	9/5	- - -	- - -	5/15	7/10	9/5	9/5	25	furrow	3/1-5/1	- - -	0.5	5/10-9/1	6/1-8/20	5-9 "	7 "	2.5-3.5	3.0
Blackeyes, 2nd crop	6/15-7/5	6/25	10/1-11/1	10/10	1200-2600 lb/ac	- - -	6/28	8/15	10/15	10/15	10	furrow	6/1-6/25	- - -	0.5	7/1-9/15	7/10-9/5	5-5 "	5 "	2.0-3.0	2.5
CITRUS																					
Navel Oranges	- - -f/	- - -f/	11/1-6/1	11/15-5/10	- - -	- - -	- - -f/	- - -f/	- - -f/	- - -f/	- - -	furrow g/	1/1-3/1	- - -	1.0	4/15-11/1	5/1-10/1	6-11 "	8 "	3.5-4.5	4.5
Valencia Oranges	- - -f/	- - -f/	4/1-7/1	4/15-6/10	- - -	- - -	- - -f/	- - -f/	- - -f/	- - -f/	- - -	furrow g/	1/1-3/1	- - -	1.0	4/15-11/1	5/1-10/1	6-11 "	8 "	3.5-4.5	4.5
COTTON	3/10-5/15	4/5	9/1-2/15	- - -h/	2-4 bls/ac	3 bls/ac	4/12	8/1	10/1	10/15	30	furrow	2/1-4/15	0.5-1.0	1.0	5/15-9/15	5/1-9/1	2-10 "	5 "	3.0-6.0	3.5
DECIDIOUS ORCHARD	- - -	- - -	- - -	- - -	- - -	- - -	3/1	6/1	10/1	11/15	15	furrow	11/1-2/15	0.5-1.5	1.0	3/15-10/1	5/1-9/1	5-9 "	7 "	3.5-6.0	4.5
FIELD CORN	3/15-5/1	4/15	8/15-10/5	9/15	1.5-2.5 tn/ac	2.5 tn/ac	4/20	7/1	9/15	9/15	25	furrow	1/15-3/15	- - -	0.3	4/1-9/15	5/1-9/1	8-13 "	11 "	3.0-6.0	3.5
GRAIN (Barley)	j/																				
Spring Grain Crop	11/1-2/1	12/1	5/16-7/15	6/1	- - -	- - -	12-10	4/1	6/1	6/1	40	border & sprinkler	10/15-1/1 k/	- - -	- - -	12/5-5/5	12/1-5/1	1-3 "	2 "	1.0-3.0	1.5
Fall Cover Crop (Green Manure)	9/1-11/1	10/1	12/1-3/1	2/1	- - -	- - -	10/5	12/1	2/1	2/1	30	border & sprinkler	8/15 10/15	- - -	1/	10/1-12/1	- - -	0-3 "	2 " m/	0.5-2.0	1.0
GRAPES	- - -	- - -	7/4-12/15	7/25-11/5	- - -	- - -	3/27	6/15	11/15	12/15	10	furrow	11/1-3/1	0.5-2.0	1.0	4/10-10/5	5/15-9/1	5-8 "	6 "	3.0-5.0	4.0
MELONS	3/1-3/25	3/1	6/20-8/1	7/5-10/5	- - -	- - -	3/7	5/1	7/1	7/1	10	furrow	1/15-3/1	- - -	1/	3/15-7/25	4/1-6/25	- - -	- - -n/	- - -	- -
MILO																					
First Crop	4/1-5/15	4/15	7/15-9/5	8/15	1.5-2.0 tn/ac	2 tn/ac	4/20	6/15	8/15	8/15	20	furrow	3/1-4/15	- - -	0.5	5/5-8/1	5/15-8/1	3-4 "	3 "	1.5-3.0	2.0
Second Crop (after barley)	6/15-7/15	7/1	9/15-11/1	10/10	- - -	- - -	7 5	3/15	10/10	10/10	20	furrow	6/1-7/1 k/	- - -	- - -	7/5-7/20	7/5-8/1	3-4 "	4 "	2.0-3.0	2.0
PASTURE, IRRIGATED	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - - -	flood	12/1-2/1	- - -	1/	3/1-11/1	every 10-14 days	- - -	- - -	4.0-6.0	5.0
POTATOES																					
Late Spring-Early o/	12/25-3/15	2/1	5/5-7/15	6/1	- - -	- - -	3/1	4/15	6/1	6/1	25	furrow p/	11/1-1/1	- - -	0.5	3/1-7/1	3/15-5/20	-daily in alt. rows	- - -	3.0-5.0	4.0
Summer Crop												sprinkler						-1-2 day intervals		1.5-2.5	2.0
Late Fall-Winter q/ Crop	7/15-9/1	8/1	11/15-3/15	12/1	- - -	- - -	8/20	9/1	12/1	12/1	15	furrow p/	6/15-8/1	- - -	0.5	8/1-10/15	8/15-10/1	daily in alt. rows r/	- - -	3.0-4.0	3.0
												sprinkler						-1-2 times wk		1.5-2.5	2.0
RICE	4/15-6/25	5/15	9/1-12/1	10/15	- - -	- - -	6/1	8/15	10/15	10/15	40	contour check	- - -	- - -	- - -	4/1-11/1	5/1-10/1	- - -s/	- - -	5.0-10.0	- -
SUGAR BEETS	12/25-3/1	12/15	6/15-9/15	8/1	- - -	- - -	2/12	5/15	8/1	8/1	30	furrow	9/1-12/1 k/	1.0 t/	1.0 k/	1/10-7/15	3/15-7/1	5-10 days	6 "	3.5-5.0	3.5
TOMATOES t/	3/15-4/15	4/1	7/15-8/15	8/1	- - -	- - -	4/10	7/1	8/1	8/1	20	furrow	2/15-3/15	- - -	0.5	4/15-8/1	5/1-7/15	6-11 "	9 "	3.0-3.5	3.0

a/ Normally a three year stand.
b/ Normally cut at thirty-day intervals between indicated dates.
c/ An unknown quantity is grazed by sheep during the winter.
d/ One cutting of hay prior to producing seed crop.
e/ Sometimes grazed by sheep in winter.
f/ Evergreen.
g/ Never plantings commonly sprinkled.
h/ 10/10-12/1 peak period.
i/ Leaf-out date.
j/ Double crop after potatoes .
k/ Usually not pre-irrigated.
l/ Unknown
m/ If not pre-irrigated.
n/ 7-10 day intervals.
o/ Representing 90% of San Joaquin Valley potato crop.
p/ Most common practice.
q/ Representing 10% of San Joaquin Valley potato crop.
r/ Early part of season and tapering off to once a week in all rows at season end.
s/ Ponded continuously with 6"-7" of water and drained two to four weeks before harvest.
t/ Mechanical harvesting.

Some of the variation in the coefficients is attributable to the limited precision of the field measurements of evapotranspiration and evaporation used in developing them. For this reason a smoothed curve was drawn through the plotted points to compensate for variations in monthly coefficients. The smoothed curves together with the arithmetic mean lines taken from Figure 12 are shown in Figure 13. The recommended coefficients are presented in Table 14.

Alfalfa - Alfalfa goes through several growing cycles of approximately one month in length, during which the ground cover varies from a low of 5 to 15 percent following cutting to a high of nearly 100 percent prior to the next cutting. Because of greater surface roughness, evapotranspiration rates of alfalfa are generally greater than pasture rates during periods of high ground cover. However, during intermittent periods of low ground cover when the transpiring surface is reduced, the evapotranspiration rates are lower than pasture. The overall effect of such changing conditions is a slightly lower monthly and annual evapotranspiration rate than for pasture.

Alfalfa evapotranspiration coefficients were based upon data collected during portions of three years near Bakersfield. These data are shown in Table 9. The monthly ET/E ratios and arithmetic means of the ratios have been plotted in Figure 12. As pointed out in Chapter III, variations in cutting-growth cycle can have pronounced effects upon evapotranspiration rates and ET/E ratios. To compensate for this effect, and for inaccuracies in field measurements, a smooth curve was drawn through the plotted monthly evapotranspiration coefficients. The arithmetic mean lines and the smoothed curves are shown in Figure 13. The adjusted monthly ET/E ratios determined from the monthly smoothed curve are listed in Table 14.

Cotton - The effect of ground cover and crop roughness on evapotranspiration rates of cotton has been discussed in Chapter II and III. Although the solid planted cotton provides greater ground cover than the skip row plantings, the total evapotranspiration for the same growing season and for the same location is only slightly greater. Also maximum evapotranspiration rates are achieved during the period of most rapid growth before it reaches maximum ground cover. Evapotranspiration rates for both solid plant and skip row cotton exceed that for pasture.

Evapotranspiration coefficients for solid planted cotton were based upon three years of record from the solid plant plus one year of record from the skip row (2x1) plant. The evapotranspiration and evaporation data used in developing the coefficients are presented in Table 10. The (2x1) skip row planting was included with the solid because the coefficients were nearly the same. The (2x2) skip row coefficients

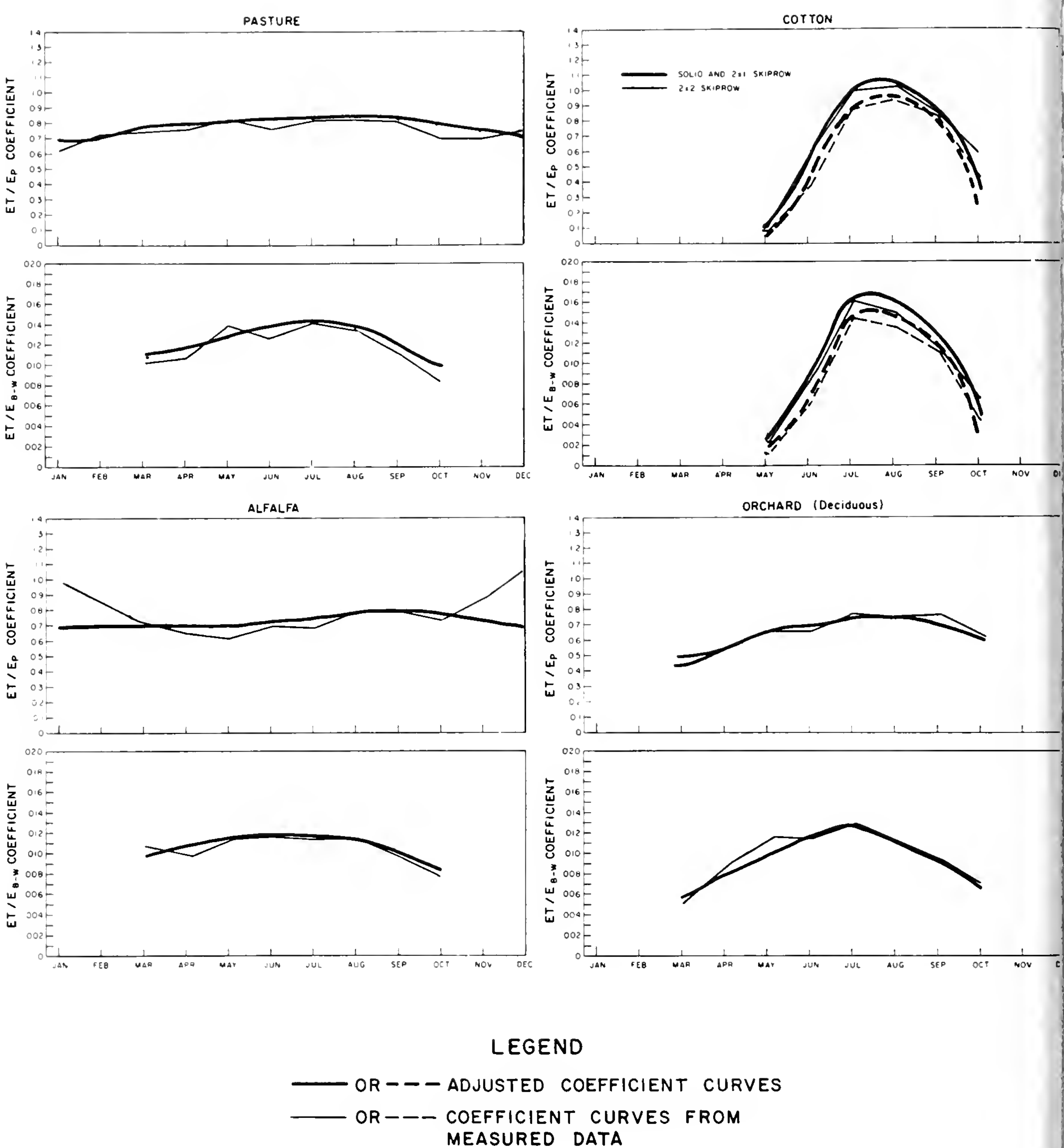


Figure 13. ADJUSTED ET/Ep RATIOS
FOR FOUR CENTRAL VALLEY CROPS

Table 14

TENTATIVE RECOMMENDED MONTHLY EVAPOTRANSPIRATION COEFFICIENTS FOR SOME PRINCIPAL CENTRAL VALLEY CROPS1/

	Pan Evapotranspiration Coefficients (ET/Ep)							
	Improved Pasture	Alfalfa (Hay)	Sugar Beets S.V. 2/	Sugar Beets S.J.V. 2/	Cotton Solid & 2x1 3/	Cotton 2x2 3/	Deciduous Orchard	Rice S.V.2/
J	0.69	0.69	0.64	-	-	-	-	(0.57)6/
F	0.70	0.70	0.48	-	-	-	-	(0.60)
M	0.75	0.70	-	0.40	-	-	0.504/	(0.35)
A	0.78	0.70	-	0.60	-	-	0.55	0.80
M	0.80	0.71	0.23	0.74	0.13	0.80	0.65	1.00
J	0.81	0.73	0.62	0.80	0.63	0.37	0.70	1.00
J	0.82	0.76	0.85	0.85	0.97	0.87	0.75	1.00
A	0.83	0.80	0.86	0.60	1.00	0.92	0.75	1.00
S	0.81	0.80	0.88	0.30	0.86	0.83	0.70	1.00
O	0.78	0.77	0.77	-	0.46	0.40	0.60	0.70
N	0.74	0.74	0.74	-	-	-	-	(0.63)
D	0.70	0.70	0.65	-	-	-	-	(0.58)
	Net Atmometer Evapotranspiration Coefficients (ET/Eb-w)							
M	0.0105	0.0100	-	0.0048	-	-	0.00605/	(0.0042)
A	0.0120	0.0108	-	0.0088	-	-	0.0085	0.0117
M	0.0133	0.0115	0.0036	0.0118	0.0020	0.0013	0.0110	0.0157
J	0.0139	0.0120	0.0111	0.0143	0.0110	0.0070	0.0120	0.0179
J	0.0140	0.0120	0.0146	0.0146	0.0167	0.0155	0.0129	0.0172
A	0.0135	0.0115	0.0139	0.0097	0.0155	0.0140	0.0111	0.0161
S	0.0120	0.0100	0.0128	0.0044	0.0115	0.0100	0.0193	0.0145
O	0.0100	0.0085	0.0103	-	0.0060	0.0045	0.0068	0.0095

1/With judgment may be used for Central Coast, Central Coastal Valleys, and Northeastern Mountain Valleys
2/S.V. - Sacramento Valley; S.J.V. - San Joaquin Valley
3/Skiprow Cotton
4/In the San Joaquin Valley, use 0.40 as coefficient
5/In the San Joaquin Valley, use 0.0052 as coefficient
6/Values in ( ) are for nongrowing season. Values may change with differences in rainfall.

were based on only one year of data. All cotton data were collected near Bakersfield. The monthly coefficients and arithmetic mean lines drawn through the points are shown in Figure 12. Smoothed curves were then visually fitted to the plotted points. The arithmetic mean lines and the smoothed curves are shown in Figure 13. The recommended coefficients determined from the smoothed curves are shown in Table 14.

Deciduous Orchard - The more important factors affecting evapotranspiration rates of orchard are crop roughness, percent ground cover, and adequacy of irrigation. The best information presently available indicates that physiological characteristics and surface roughness are quite similar between species of deciduous orchards.

Evapotranspiration coefficients were based upon data collected in a plum orchard near Bakersfield during portions of five years. These data are presented in Table 11. The observed monthly ratios of ET/E and arithmetic mean lines drawn through them are shown in Figure 12. Smoothed curves were then drawn through the plotted points to develop the recommended coefficients presented in Table 14. The arithmetic mean lines and smoothed curves are shown in Figure 13.

Sugar Beets - Sugar beets are planted and harvested at different times in the Central Valley. In the Sacramento Valley, the normal growing season starts in mid-April and extends through a three-month harvest period beginning in December and ending in March. In the San Joaquin Valley, the crop typically is planted in mid-February and harvested between the end of July and early October. As the crop approaches maximum ground cover, the evapotranspiration rate exceeds potential evapotranspiration. Although monthly evapotranspiration for beets in the two areas vary greatly (see Table 16) the total evapotranspiration show a difference of less than 10 percent.

Coefficients were based upon one year of field data collected by W. O. Pruitt of the University of California and presented in his 1959-60 annual report entitled "Correlation of Climatological Data with Water Requirements of Crops". Measured evapotranspiration data shown in that report were accumulatively plotted. From the accumulative curve, monthly evapotranspiration values were determined and then used with measured monthly pan evaporation for corresponding periods to obtain monthly ET/Ep ratios. ET/Eb-w ratios were derived using the Davis evapotranspiration data and average atmometer evaporation data for the Central Valley. The monthly evapotranspiration coefficients are shown in Table 14.

Rice - Most of the rice in the State is grown in the Sacramento Valley. The fields are flooded and rice planted usually sometime between April 15 and the first week of May. May 20 is generally considered the latest planting date for a crop to be assured. Water is cut off around September 10 with harvest beginning the latter part of September or the early part of October. Thus far no attempts have been made by the Department to measure the actual evapotranspiration of rice. To develop monthly evapotranspiration coefficients for this important crop, it was necessary to devise a different method from that described for the other crops. First, estimates of annual evapotranspiration were made from an analysis of applied water and runoff data on rice fields. The applied water and return flow data collected from various sources, indicate the annual evapotranspiration of rice to be approximately five feet per year.

This estimated annual evapotranspiration was distributed by months using the following assumptions. (1) For the growing season months of May through September evapotranspiration rates equal evaporation from a standard Weather Bureau Class A pan operated in an irrigated pasture environment. (2) In October, following the drainage of the fields and harvest, evapotranspiration is the same as pasture because of evaporation from the still moist, fine textured soils. (3) During the period of November through February, rainfall in the Sacramento Valley tends to keep the soils fairly moist and evaporation from the bare soil plus evapotranspiration from wild growth are about 85 percent of potential evapotranspiration. (4) In March when rainfall is less and the ground is being prepared for seeding, the soil surface becomes fairly dry and the evapotranspiration decreases to 50 percent of potential evapotranspiration. (5) During April, when the fields are being flooded, the evapotranspiration rate is equal to potential evapotranspiration.

ET/E ratios were determined by relating the estimated monthly evapotranspiration to the average Central Valley pan and net atmometer evaporation data. These recommended coefficients are shown in Table 14.

Nongrowing Season Evapotranspiration

During the nongrowing season, evaporation and transpiration from weeds and bare ground will use a small amount of moisture. This moisture must be added to that used during the growing season to estimate the total amount of water consumed during the year. The amount of water evaporated from bare ground or transpired by unwanted vegetation is dependent upon the evaporation demand or availability of water at the soil surface and in the root zone to meet that demand. The availability of water is determined by the amount of carryover irrigation water and/or rainfall. The use of potential

evapotranspiration provides a reasonable upper limit for estimating total evaporation during the nongrowing season.

Procedure for Calculating Monthly Evapotranspiration

The sample calculation shown on Table 15 demonstrates the method used in estimating monthly evapotranspiration of deciduous orchards for growing and nongrowing season periods within two areas of the Central Valley. The areas selected were near Red Bluff in the northern Sacramento Valley and near Bakersfield in the southern San Joaquin Valley. They were chosen to demonstrate the variability in monthly and growing season evapotranspiration rates that can occur with different rainfall conditions.

During the growing season monthly evapotranspiration values were estimated for both areas by multiplying the average pan evaporation data for the Central Valley by the pan evapotranspiration coefficients derived at Bakersfield. During the nongrowing season, difference in evapotranspiration between the two areas is attributable to difference in precipitation, since both areas experience essentially the same evaporative demand. The Red Bluff area receives 22.0 inches of annual precipitation while the Bakersfield area receives only 6.4 inches. The greater precipitation in the northern end of the valley not only results in higher wintertime evaporation rates than in the southern valley, but also in transpiration losses by supporting the growth of weeds and cover crops. As a result, winter evapotranspiration rates are due to both evaporation and transpiration.

Table 16 presents tentative recommended monthly growing season evapotranspiration values for pasture, alfalfa, sugar beets, cotton, and rice in addition to the deciduous orchards. These values have been plotted in Figure 14.

Procedure for Calculating Evapotranspiration of Applied Water and Precipitation

In the previous section, a procedure for estimating monthly evapotranspiration was presented. Although monthly evapotranspiratio values are adequate to the needs of a hydrologist making estimates of historic and future runoff, they are of little value to a planner making estimates of irrigation requirements. For this latter purpose, the planner needs to know the amounts of evapotranspiration of applied water and rainfall that make up the total. In this section, a method of partitioning the total evapotranspiration into these components is presented.

Table 15

CALCULATIONS OF MONTHLY EVAPOTRANSPIRATION

Deciduous Orchards - Central Valley

Season	Month	Northern Sacramento Valley near Red Bluff			Southern San Joaquin Valley near Bakersfield		
		Precipitation 1/ (inches)	Potential ET 2/ (inches)	Estimated ET 3/ (inches)	Precipitation 1/ (inches)	Potential ET 2/ (inches)	Estimated ET 3/ (inches)
Non-growing season	Nov	2.3	1.6	1.6	0.5	1.6	0.5
	Dec	4.2	0.8	0.8	1.0	0.8	0.8
	Jan	4.3	1.0	1.0	1.2	1.0	1.0
	Feb	3.3	1.8	1.8	1.1	1.8	1.5
			Subtotals	5.2			3.8
Season	Month	Pan Evaporation (inches)4/	Pan Coefficient 5/	Estimated ET (inches)	Pan Evaporation (inches)4/	Pan Coefficient 5/	Estimated ET (inches)
Growing season	Mar	4.0	0.50	2.0	4.0	0.40	1.6
	Apr	6.0	0.55	3.3	6.0	0.55	3.3
	May	7.6	0.65	4.9	7.6	0.65	4.9
	Jun	9.6	0.70	6.7	0.6	0.70	6.7
	Jul	10.0	0.75	7.5	10.0	0.75	7.5
	Aug	8.5	0.75	6.4	8.5	0.75	6.4
	Sep	6.4	0.70	4.5	6.4	0.70	4.5
	Oct	4.5	0.60	2.7	4.5	0.60	2.7
			Subtotals	38.0			37.6
			TOTALS	43.0			41.4

1/ Thirty year USWB average (January 1931 - December 1960) for Red Bluff and Bakersfield.

2/ Calculated from recommended pan coefficients and average Central Valley pan evaporation. ET = Ep X pan coefficient.

3/ Either precipitation plus accumulated excess of precipitation over PET from previous months or potential evapotranspiration, whichever is less.

4/ From Central Valley pan transect, Plate 1.

5/ From Table 14 "Tentative Recommended Monthly Evapotranspiration Coefficients for Some Principal Central Valley Crops".

Table 16
TENTATIVE RECOMMENDED MONTHLY EVAPOTRANSPIRATION VALUES FOR SOME PRINCIPAL CENTRAL VALLEY CROPS 1/
(in inches)

Month	Improved Pasture PET	Alfalfa (Hay)	Sugar Beets		Cotton		Deciduous Orchard	Rice S.V. 2/
			S.V. 2/	S.J.V. 2/	Solid& 2x1 3/	2x2 3/		
JAN	1.0	1.0	0.9	-	-	-	-	(0.8) 5/
FEB	1.8	1.8	1.2	-	-	-	-	(1.5)
MAR	3.0	2.8	-	1.6	-	-	4/	(1.4)
APR	4.7	4.2	-	3.6	-	-	3.3	4.8
MAY	6.1	5.4	1.8	5.6	1.0	0.6	4.9	7.6
JUN	7.8	7.0	6.0	7.7	6.0	3.6	6.7	9.6
JUL	8.2	7.6	8.5	8.5	9.7	8.8	7.5	10.0
AUG	7.1	6.8	7.3	5.1	8.5	7.8	6.4	8.5
SEP	5.2	5.1	5.6	1.9	5.5	5.3	4.5	6.4
OCT	3.5	3.5	3.5	-	2.1	1.8	2.7	3.2
NOV	1.6	1.6	1.6	-	-	-	-	(1.4)
DEC	0.8	0.8	0.8	-	-	-	-	(0.8)
Total	50.8	47.6	37.2	34.0	32.8	27.9	4/	56.0
(Feet)	4.2	4.0	3.1	2.8	2.7	2.3		4.7

1/ Calculated from mean monthly pan evaporation (Plate 1) and recommended pan evapotranspiration coefficients Table, 14 Use of atmometer evapotranspiration coefficients gives similar results.

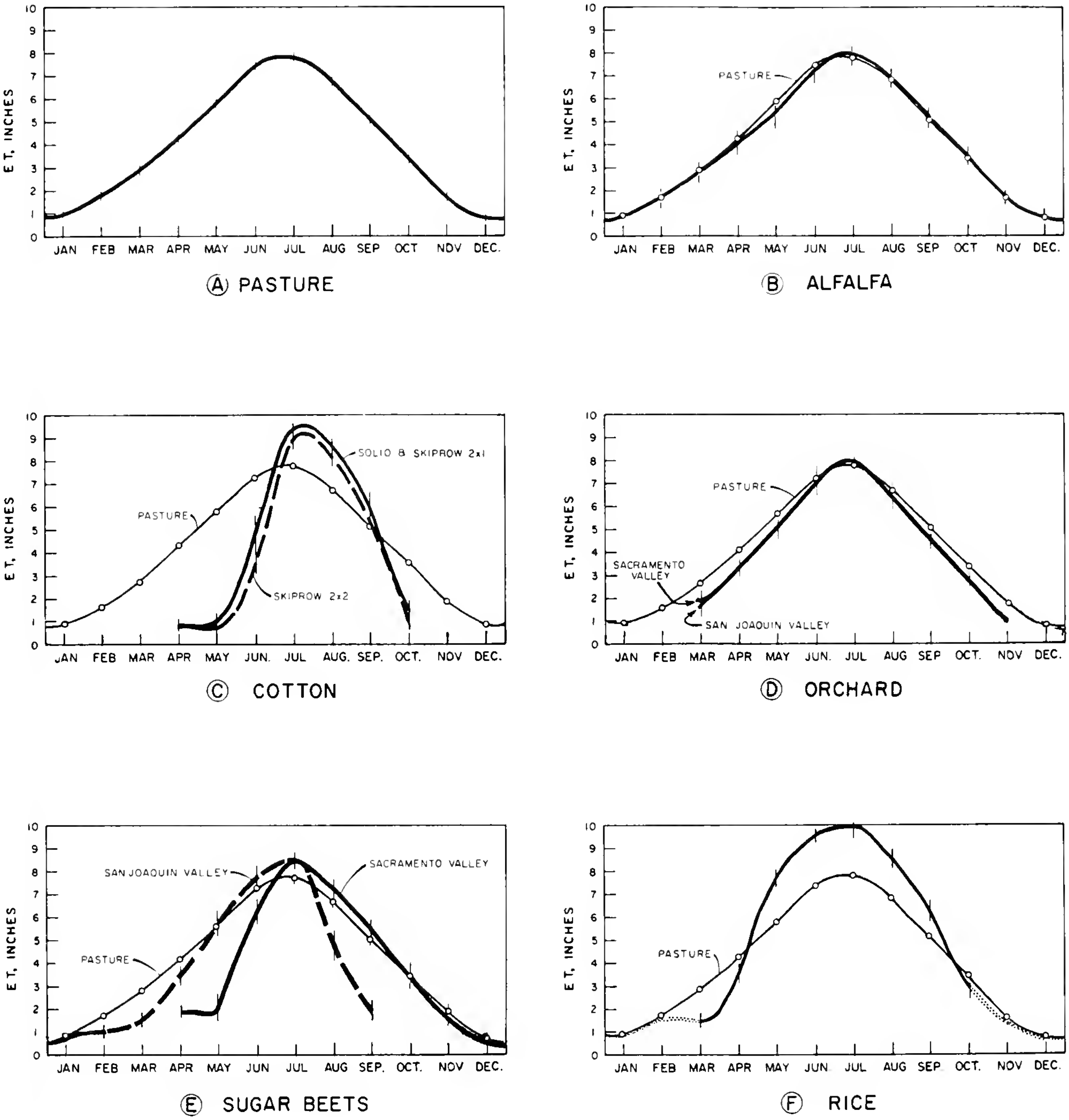
2/ SV - Sacramento Valley, SJV - San Joaquin Valley

3/ Skiprow Cotton

4/

		SV		SJV
March	-	2.0	-	1.6
Total	-	38.0	-	37.6
(Feet)	-	3.2	-	3.1

5/ Values in ( ) are for nongrowing season. Values may change with differences in rainfall.



NOTES:

(1) PASTURE HAS BEEN INCLUDED ON EACH GRAPH FOR COMPARISON PURPOSES. THIS IS CONSIDERED THE POTENTIAL ET FOR THE CENTRAL VALLEY.

(2) DOTTED LINES INDICATE NONGROWING SEASON. VALUES MAY CHANGE WITH DIFFERENCES IN RAINFALL.

Figure 14. ESTIMATED MONTHLY EVAPOTRANSPIRATION FOR SEVERAL CENTRAL VALLEY CROPS

Basic Procedure - The procedure consists of making assumptions on effective root zone, available soil moisture capacity, and ground cover conditions and then using the assumptions along with precipitation and evapotranspiration data to maintain a budget, or running account, of soil moisture accretions and depletions.

To simplify the budgeting procedure, the soil moisture level at the end of the irrigation season is used to establish the account. This is generally the time when moisture in storage is at its lowest. When actual end-of-the-irrigation season soil moisture data are not available, they are estimated. From this point on, a strict monthly accounting of precipitation and/or applied water is made, showing how much water (1) directly contributes to evapotranspiration, (2) goes into storage, and (3) either runs off or percolates below the root zone.

The available moisture-holding capacity of the soil can be greatly affected by irrigation practices and the extent to which the farmer uses the stored moisture during the irrigation season. When farmers maintain their fields at a high-moisture level throughout the irrigation season, the use of stored moisture may be small. The change in soil moisture storage between the beginning and the end of the irrigation season is a measure of the use of stored soil moisture. Although detailed information on the use of stored soil moisture under current irrigation practices is limited, general estimates can be made of such use. In the table below, recommended depletion levels, at various rooting depths for an "average" soil are presented.

Crop Class	Effective Rooting Depth	Available Soil Moisture Capacity	Available Soil Moisture Assumed Depletion
Shallow rooted	1' - 3'	$1\frac{1}{2}$" per ft.	75% for annuals
		$1\frac{1}{2}$" " "	50% for perennials
Medium rooted	3' - 6'	$1\frac{1}{2}$" per ft.	75% for annuals
		$1\frac{1}{2}$" " "	50% for perennials
Deep rooted	6' +	$1\frac{1}{2}$" per ft.	75% for annuals
		$1\frac{1}{2}$" " "	50% for perennials

As may be noted, annual crops make greater use of stored soil moisture than perennial crops. Studies presently underway will permit better estimates in the future of effective rooting depths and soil moisture use for individual crops.

Example of Basic Procedure - Deciduous orchard is used in this example just as in the discussion of a procedure for calculating monthly evapotranspiration. The data, assumptions, and results for the crop in the Sacramento Valley and in the San Joaquin Valley are presented in Table 17.

An analysis of the results shows that nongrowing season rainfall increases the nongrowing season evapotranspiration during that time. The primary benefit of an increase of rainfall, however, is the reduction of evapotranspiration of applied water during the growing season. This is shown in Table 17 where the 22 inch annual rainfall in the Red Bluff area results in evapotranspiration of applied water 10 inches less than in the San Joaquin Valley.

The results for the growing season evapotranspiration in the Sacramento Valley are based on the assumption that only 50 percent of the available soil moisture is utilized. This moisture is stored during the nongrowing season, partially utilized at the start of the growing season, maintained at a fairly high level by irrigation during the growing season, and completely utilized during the last three months of the growing season. These assumptions are based on limited field measurements of moisture conditions during and at the end of the irrigation season.

In the San Joaquin Valley, there normally is no nongrowing season precipitation which can be stored and carried over into the growing season. The available soil moisture in the soil is normally brought up to a fairly high level prior to the growing season by preirrigation. Thus, the only precipitation that can be considered effective is that which occurs during the growing season.

Estimates of Evapotranspiration of Applied Water

Estimates of the evapotranspiration of applied water for other important crops considered in this report have also been determined by using the procedure described above. These values are shown in Table 18 and were used in the preparation of Tables 1 and 2 in Chapter I to compare the current unit and total evapotranspiration of applied water values with those used in Bulletin No. 2.

It is possible to vary the level of available soil moisture by various water management practices. This can affect individual monthly estimates of evapotranspiration of applied water. Annual values, however, are less affected by these management practices. As more information is gained concerning irrigation practices, the monthly use of evapotranspiration of applied water can be estimated with greater reliability.

Table 17

CALCULATIONS OF EVAPOTRANSPIRATION OF APPLIED WATER AND PRECIPITATION

Deciduous Orchards - Central Valley

(All values in inches)

Season	Month	Northern Sacramento Valley Near Red Bluff									Southern San Joaquin Valley Near Bakersfield								
			Precipitation (Inches)									Precipitation (Inches)							
		Estim. ET1/	Mean2/ Precip.	Direct ET of Precip.	Precip. into Storage	ET of Stored Precip.	Precip. Available in3/ Storage	Deep Perco. and Runoff	Total ET of Precip.	ET of Applied Water	Estim. ET1/	Mean2/ Precip.	Direct ET of Precip.	Precip. into Storage	ET of Stored Precip.	Precip. Available in3/ Storage	Deep Perco. and Runoff	Total ET of Precip.	ET of Applied Water
Non-Growing Season	Nov.	1.6	2.3	1.6	0.7	0.0	0.7	0.0	1.6	0.0	0.5	0.5	0.5	-	0.0	0.0	0.0	0.5	0.0
	Dec.	0.8	4.2	0.8	3.4	0.0	4.1	0.0	0.8	0.0	0.8	1.0	0.8	0.2	0.0	0.2	0.0	0.8	0.0
	Jan.	1.0	4.3	1.0	1.9	0.0	6.0	1.4	1.0	0.0	1.0	1.2	1.0	0.2	0.0	0.4	0.0	1.0	0.0
	Feb.	1.8	3.3	1.8	0.0	0.0	6.0	1.5	1.6	0.0	1.5	1.1	1.1	0.0	0.4	0.0	0.0	1.5	0.0
Subtotals		5.2	14.1	5.2	6.0	0.0	-	2.9	5.0	0.0	3.8	3.8	3.4	0.4	0.4	0.0	0.0	3.8	0.0
Growing Season	Mar.	2.0	2.7	2.0	0.0	0.0	6.0	0.7	2.0	0.0	1.6	1.1	1.1	0.0	0.0	0.0	0.0	1.1	0.5
	Apr.	3.3	1.8	1.8	0.0	0.5	5.5	0.0	2.3	1.0	3.3	0.8	0.8	0.0	0.0	0.0	0.0	0.8	2.5
	May	4.9	1.1	1.1	0.0	2.0	3.5	0.0	3.1	1.8	4.9	0.2	0.2	0.0	0.0	0.0	0.0	0.2	4.7
	Jun.	6.7	0.4	0.4	0.0	0.0	3.5	0.0	0.4	6.3	6.7	0.1	0.1	0.0	0.0	0.0	0.0	0.1	6.6
	Jul.	7.5	0.0	0	0.0	0.0	3.5	0.0	0.0	7.5	7.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.5
	Aug.	6.4	0.1	0.1	0.0	0.5	3.0	0.0	0.6	5.8	6.4	T	0.0	0.0	0.0	0.0	0.0	0.0	6.4
	Sep.	4.5	0.4	0.4	0.0	2.0	1.0	0.0	2.4	2.1	4.5	0.1	0.1	0.0	0.0	0.0	0.0	0.1	4.4
	Oct.	2.7	1.4	1.4	0.0	1.0	0.0	0.0	2.4	0.3	2.7	0.3	0.3	0.0	0.0	0.0	0.0	0.3	2.4
Subtotals		38.0	7.9	7.2	0.0	6.0	-	0.7	13.2	24.8	37.6	2.6	2.6	0.0	0.0	-	0.0	2.6	35.0
Annual Totals		43.0	22.0	12.4	6.0	6.0	-	3.6	18.2	24.8	41.4	6.4	6.0	0.4	0.4	-	0.0	6.4	35.0

1/From Table 15, "Calculations of Monthly Evapotranspiration, Deciduous Orchards - Central Valley".
2/Thirty year USWB mean for Red Bluff and Bakersfield.
3/Maximum available precipitation in storage not to exceed 6 inches (50% of total) because 6 inches of applied water is assumed to be in storage at end of the growing season.

Assumptions:
a. Effective root zone depth - 8 feet.
b. Available soil moisture capacity - 1.5 inches per foot of depth.
c. Total available soil moisture capacity - 12 inches.
d. Available soil moisture at end of growing season - 50% of total (6 inches).
e. Wintertime ground cover conditions in San Joaquin Valley. bare ground; in Sacramento Valley, weeds and cover crops.

Table 18

ESTIMATES OF EVAPOTRANSPIRATION OF APPLIED WATER FOR SEVERAL CENTRAL VALLEY CROPS

(In Inches)

Month	Average Precipitation			Improved Pasture				Alfalfa				Sugar Beets				
				Total ET	ET of Applied Water			Total ET	ET of Applied Water			Total ET		ET of Applied Water		
	2/ S.V.	S.J.	T.L.	C.V.	S.V.	S.J.	T.L.	C.V.	S.V.	S.J.	T.L.	S.V.	S.J. &T.L.	S.V.	S.J.	T.L.
JAN	3.2	2.2	1.6	1.0	-	-	-	1.0	-	-	-	0.9	-	-	-	-
FEB	3.0	2.1	1.6	1.8	-	-	-	1.8	-	-	-	1.2	-	-	-	-
MAR	2.2	1.8	1.4	3.0	0.5	1.0	1.5	2.8	0.3	0.5	1.1	-	1.6	-	-	-
APR	1.3	1.2	0.9	4.7	3.0	3.2	3.5	4.2	2.0	2.4	2.8	-	3.6	-	2.0	2.5
MAY	0.6	0.4	0.2	6.1	5.2	5.5	-	5.4	4.0	5.0	5.2	1.8	5.6	0.7	4.5	5.0
JUN	0.2	0.1	0.1	7.8	7.6	7.7	7.7	7.0	6.5	6.5	6.9	6.0	7.7	5.0	7.0	7.5
JUL	0.0	0.0	0.1	8.2	8.2	8.2	8.1	7.6	6.5	6.5	7.5	8.5	8.5	8.5	8.5	8.4
AUG	0.0	0.0	0.0	7.1	7.1	7.1	7.1	6.8	6.5	6.5	6.8	7.3	5.1	7.3	4.5	5.0
SEP	0.2	0.2	0.1	5.2	4.5	4.5	4.6	5.1	4.5	4.9	5.0	5.6	1.9	4.3	1.0	1.4
OCT	0.8	0.5	0.4	3.5	2.7	2.8	2.9	3.5	2.5	3.0	3.1	3.5	-	1.0	-	-
NOV	1.6	1.0	0.7	1.6	-	0.5	0.9	1.6	-	0.6	0.9	1.6	-	-	-	-
DEC	3.7	2.2	1.5	0.8	-	-	-	0.8	-	-	-	0.8	-	-	-	-
TOTAL	16.8	11.7	8.6	50.8	38.8	40.5	42.2	47.6	32.8	35.9	39.3	37.2	34.0	26.8	27.5	29.8

Month	Cotton-Solid Plant			Cotton-Skiprow			Deciduous Orchard				Rice	
	Total ET	ET of Applied Water		Total ET	ET of Applied Water		Total ET	ET of Applied Water			Total ET	ET of Applied Water
	C.V.	S.J.	T.L.	C.V.	S.J.	T.L.	C.V.	S.V.	S.J.	T.L.	C.V.	S.V.
JAN	-	-	-	-	-	-	-	-	-	-	0.8	-
FEB	-	-	-	-	-	-	-	-	-	-	1.5	-
MAR	-	-	-	-	-	-	2.0 3/	-	-	-	1.4	-
APR	-	-	-	-	-	-	3.3	1.0	1.5	1.9	4.8	3.5
MAY	1.0	-	-	0.6	-	-	4.9	4.0	4.0	4.7	7.6	7.6
JUN	6.0	5.4	5.9	3.6	3.0	3.5	6.7	6.0	6.6	6.6	9.6	9.6
JUL	9.7	9.0	9.6	8.8	8.0	8.7	7.5	7.5	7.5	7.4	10.0	10.0
AUG	8.5	8.5	8.5	7.8	7.8	7.8	6.4	6.4	6.4	6.4	8.5	8.5
SEP	5.5	5.3	5.4	5.3	4.5	4.8	4.5	2.0	3.8	4.4	6.4	6.4
OCT	2.1	-	1.1	1.8	-	0.8	2.7	-	0.7	1.8	3.2	3.2
NOV	-	-	-	-	-	-	-	-	-	-	1.4	-
DEC	-	-	-	-	-	-	-	-	-	-	0.8	-
TOTAL	32.8	28.2	30.5	27.9	23.3	25.6	38.0	26.9	30.5	33.2	56.0	48.8

1/ Average precipitation is based upon USWB 30 year mean for the period 1931-1960 at representative stations within each area:

Sacramento Valley: Willows, Knights Landing, Colusa
San Joaquin Valley: Merced, Madera, Modesto
Tulare Lake Basin: Bakersfield, Fresno, Hanford

2/ S.V. Sacramento Valley
S.J. San Joaquin Valley
T.L. Tulare Lake Basin
C.V. Central Valley

3/ Use 1.6 for San Joaquin Valley and Tulare Lake Basin

CHAPTER V. PRIMARY FACTORS AFFECTING ESTIMATES OF IRRIGATION REQUIREMENTS

The component parts of monthly evapotranspiration were shown to be (1) Evapotranspiration of Applied Water, and (2) Evapotranspiration of Precipitation. By management of available soil moisture storage the farmer can greatly influence the use of applied water or precipitation. Therefore it must be recognized that these values vary from month to month and from year to year. Based upon assumptions of average practices, however, reasonable estimates of monthly irrigation requirements can be made.

The principal problem to the accomplishment of this task is the estimation of irrigation efficiencies.

Irrigation Efficiencies

The efficiency with which a farmer applies irrigation water is influenced by many factors. Technically irrigation efficiency is the quantity of applied water retained within the root zone of a crop compared to the total applied water. This efficiency can be for a single irrigation or for the whole season. It can relate to a single field or to an entire service area. Because it has been easier to estimate evapotranspiration between periods than to estimate the quantity of water retained within the root zone, irrigation efficiencies have commonly been referred to as the relationship of evapotranspiration of applied water to total applied water. On a total growing season basis, it makes little difference which procedure is used. The estimation of monthly or short period irrigation efficiencies, however, becomes complicated. Efficiencies based upon the evapotranspiration of applied water that do not allow for changes in the soil moisture storage within the root zone can be misleading. Efficiencies measured on a single irrigation or crop do not necessarily mean that moisture is being lost by deep percolation or return flow since it simply may be going into soil moisture storage. In the latter case, the water can be used by the same or succeeding crop. By any method, the indication of a high or low irrigation efficiency does not guarantee that the crop always has sufficient available moisture. Frequency of irrigation is an important factor, as well as efficiency, in maintaining soil moisture content for optimum plant growth.

Regardless of which method is followed for estimating irrigation efficiency, it must be recognized that efficiencies vary for different crops on the same soil, for the same crops on different soils, and for different irrigation practices. Furthermore, efficiencies may vary throughout the season. Based upon the present state of knowledge, however, it appears best to assume that the irrigation efficiency is constant throughout the season.

For purposes of calculating applied or irrigation water requirements, an estimate must also be made regarding the usual and practically attainable irrigation efficiencies. By applying this estimate to the evapotranspiration of applied water values shown in Table 18, Chapter IV, monthly irrigation requirements can be calculated. It is estimated that as a general rule, the use of an irrigation efficiency of 50-70 percent can be assumed for most crops within the Central Valley. This will give satisfactory estimates of present water requirements. Future irrigation efficiencies are assumed to be ten percent higher due to improved irrigation practices. Applied water measurements, where available, can be used to provide a rough check on these estimates of irrigation requirements.

Applied Water Data

Records of applied water from individual farmers demonstrate very large variations in the total quantity of applied water and in the patterns of application. For this reason, there is considerable question as to the validity of using applied water measurements for estimating irrigation requirements. Such data, however, are useful in giving some idea of the general irrigation practice. Where evapotranspiration measurements have been made, applied water measurements can be used to indicate the irrigation efficiency being obtained.

Studies have shown that the amount of water applied to different crops varies widely because of different methods of irrigation, types of soils, depth of rooting zone of crops, and cost and amount of available water supply. Where water is abundant and cheap, farmers often believe it to be more economical to use an excess of water than to pay the expense of developing an efficient farm irrigation system. On the other hand, in areas where the availability of water is short in relation to the quantity of irrigated or irrigable land, farmers often find it more economical and in the best interests of the area to irrigate as efficiently as possible. An important consideration in water deficient areas is the possibility for the reuse of excess irrigation water.

Net Water Use

By reuse of excess applied irrigation water, the total quantity of water necessary to meet the applied water requirement of an area may be reduced. Net water use is the total evapotranspiration of applied water plus irrecoverable losses. Irrecoverable losses are the result of all conditions which make the water unavailable, uneconomical, or unfit for reuse. Included are deep percolation or return flow which enter water bodies unfit for use, such as the ocean or saline ground water basins. Water which by absorption of minerals or toxic ions become unfit for reuse, are also irrecoverable. Recoverable

supplies include that portion of the excess applied water which becomes available for reuse by (1) deep percolation into usable ground water basins or (2) recapture of surface runoff through sump pumps or rediversion from the surface streams.

The availability of water for reuse is closely tied to the question of attainable and actual irrigation efficiencies and practices. There are presently very little data available upon which reliable determinations of net water use for a particular farm or small area can be made. Future studies will be geared to obtaining this type of information.

APPENDIX A

DEFINITION OF TERMS

APPENDIX A

Definition of Terms

Advection - The horizontal transport of an air mass which results primarily in a change in air temperature.

Advective Energy - The energy gained or lost to a surface due to advection.

Agroclimatic - Climatic conditions within an agricultural or vegetated area that influence or are influenced by the agriculture of the area.

Agroclimatic Station - A small site, normally irrigated and grass covered having a prescribed exposure in which instruments are placed to measure selected climatic variables under conditions representative of an irrigated agricultural environment. May also refer to stations designed to measure agroclimatic variables in dryland and native vegetation environments.

Applied Water Requirement (Irrigation Requirement) - The depth of water per unit area required to be delivered to a field headgate for a crop in a given period of time. It does not include direct precipitation.

Atmometer - See "Evaporimeter". In this report atmometer refers to Livingston black and white porous porcelain spheres.

Atmometer Evapotranspiration Coefficient (ET/E_{b-w}) - A numerical ratio of the depth of water, in inches, evapotranspired by a a given crop divided by the amount of net atmometer evaporation, in milliliters, measured in the vicinity of the crop during the same time period.

Atmometer Evaporation - Evaporation of water from Livingston black or white atmometers, measured in milliliters.

Available Moisture - The amount of water held in the soil that can be extracted by a crop. Often expressed in inches per foot of soil depth.

Consumptive Use - See "Evapotranspiration".

Drainage - The process by which excess water is removed from an area either through the soil or over the land surface.

Effective Precipitation - That portion of precipitation evapotranspired during the growing season which reduces the applied water requirement.

Effective Root Zone - The depth of soil material through which plant roots readily penetrate to obtain water and plant nutrients.

Energy Balance - The equilibrium which is known to exist when all sources of heat gain and loss for a given region or body are accounted for. In general, this balance includes advective and evaporative terms as well as a radiation term.

ET - See "Evapotranspiration".

ET Tanks - See "Evapotranspirometer".

ET/E-Coefficient - The numerical ratio of the depth of water in inches lost from a crop through evapotranspiration (ET) divided by an evaporation value (E), in inches or milliliters. The evaporation value, considered an index of evaporative demand, is measured in the vicinity of the crop under carefully standardized conditions during the same time period as the evapotranspiration occurs.

Evaporation Pan - See "Evaporimeter". In this report "evaporation pan" refers to a U. S. Weather Bureau Class A evaporation pan. See "U. S. Weather Bureau Pan".

Evaporative Demand - The collective influence of all climatic factors on the rate of evaporation of water.

Evaporimeter - Any instrument for measuring or estimating evaporative demand.

Evapotranspiration (ET) - The quantity of water transpired by plants; retained in plant tissue; and evaporated from plant foliage from surrounding surfaces, and from adjacent soil, in a specified time period. Usually expressed in depth of water per unit area. As used here, evapotranspiration is synonymous with consumptive use.

Evapotranspirometer (Lysimeter, ET Tanks) - A device confining a soil mass of known dimensions in such a manner that measurements of evapotranspiration from the specific soil mass may be made. Provision is made in the system for the periodic or continuous determination of the amount of water removed.

Fetch - Upwind distance to an abrupt change in site environment.

Field Capacity - The volume of water remaining in a well-drained soil when velocity of downward flow into unsaturated soil has become negligible. It is expressed as a percentage of weight of oven dry soil or as a soil moisture tension value.

Ground Cover Percentage - The percentage of a specified area covered or shaded by transpiring vegetation, when viewed from directly overhead.

Growing Season - A period during which crops experience their greatest growth and water use.

Irrigation Efficiency - The percentage of the total amount of water applied that is directly evaporated from soil and plant surfaces or retained within the root zone to be transpired at a later time.

Irrigation Requirement - See "Applied Water Requirement".

Lysimeter - See "Evapotranspirometer".

Moisture Stress - A condition where the evaporative demand exceeds the ability of the soil-plant system to meet that demand.

Net Atmometer Evaporation (E_{b-w}) - The difference between black atmometer evaporation and white atmometer evaporation, expressed in milliliters.

Net Radiation - The total incoming minus the total outgoing radiation. This radiation is the principle energy source necessary for vaporization of water in the evapotranspiration process.

Net Water Use - Evapotranspiration of applied water plus irrecoverable losses.

Neutron Probe - An instrument, based upon the principle of neutron moderation, for determination of soil moisture content.

Neutron Scattering Technique - A method of determining soil moisture content using neutron-emitting radioactive materials. The method is based on the fact that when fast moving neutrons meet hydrogen atoms they are moderated to "slow neutrons" and scattered. Since hydrogen atoms in the soil are associated almost exclusively with water, the number of slow neutrons returning to the vicinity of the detector tube is directly proportional to the amount of moisture in the surrounding soil.

Pan - See "Evaporation Pan".

Pan Evapotranspiration Coefficient (ET/E_p) - A numerical ratio of the depth of water, in inches, evapotranspired by a given crop divided by the depth of water, in inches, evaporated from an evaporation pan in the vicinity of the crop during the same time period.

Pan Evaporation (E_p) - Evaporation of water from a U. S. Weather Bureau evaporation pan.

Percent Ground Cover - See "Ground Cover Percentage".

Permanent Wilting Percentage (PWP) - The soil moisture content below which plants cannot readily obtain water. It is the soil-moisture condition at which plants wilt and fail to recover turgidity when placed in a dark, humid chamber. Generally expressed as the percentage of soil moisture based on the dry weight of the soil. Also called Permanent Wilting Point.

PET - See "Potential Evapotranspiration".

Phreatophyte - A plant that habitually obtains its water supply from the zone of saturation, either directly or through the capillary fringe.

Potential Evapotranspiration (PET) - The amount of water that can be transpired by low growing green crop of about the same color as grass, which completely covers the ground, has an unlimited supply of water and an extensive fetch.

Riparian Vegetation - Vegetation growing on the banks of a stream or other body of water.

Soil Moisture - The water in soils. Usually expressed as a percentage of the dry weight of the soil. Can also be expressed on a wet weight or volume basis.

Soil Moisture Change (Soil Moisture Depletion) - Normally, the loss in soil moisture in unit time resulting from transpiration, surface evaporation, and deep percolation. The change may become a positive value as a result of precipitation or irrigation. It differs from evapotranspiration in that it does not include evaporation of rainfall intercepted by foliage, but does consider deep percolation.

Soil Moisture Deficiency - The amount of water required to raise the soil moisture within the root zone from a given content to field capacity.

Solar Radiation - Essentially short-wave energy originating from the sun. Solar radiation is the earth's principle source of energy.

Tensiometer - A device for measuring soil moisture suction. Most tensiometers operate between the limits of zero and approximately 0.8 atmospheres.

Transpiration - The process by which water vapor is transferred to the atmosphere through living plants.

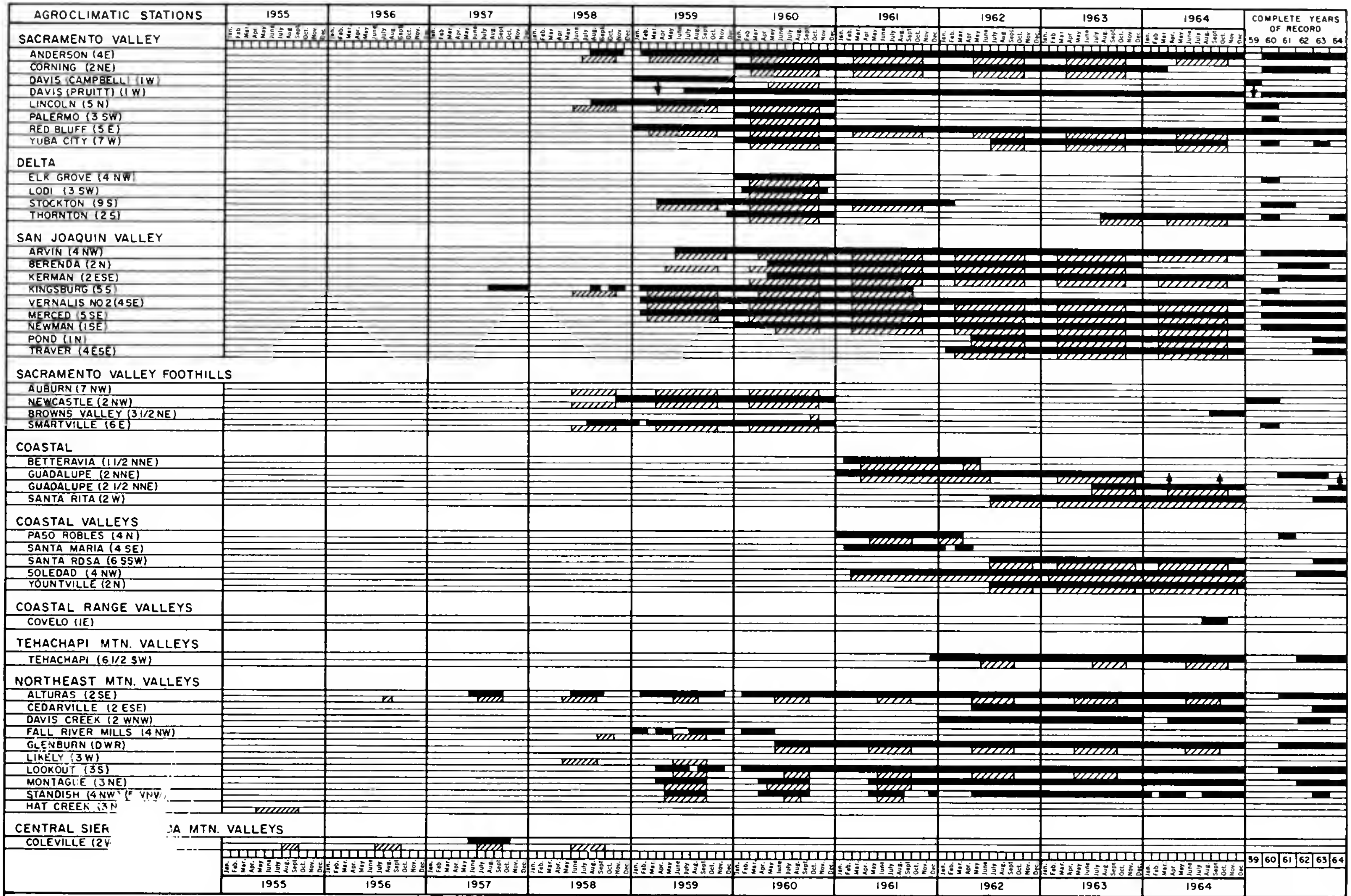
Unit Water Use (Unit Value of Water Use) - The amount of water used by a specific crop, type of native vegetation, or non-vegetated surface, expressed as a depth per unit area; for example acre-feet per acre.

U. S. Weather Bureau Pan (Class A) - An open-topped metal container four feet in diameter and 10 inches deep used to measure evaporation rates of water.

Water Requirement (Agricultural) - The depth of water needed by a crop in a given period of time to satisfy all beneficial uses and to meet all irrecoverable losses incidental to such uses. Includes effective precipitation.

APPENDIX B

AVAILABILITY OF HISTORIC MONTHLY EVAPORATION DATA



LEGEND

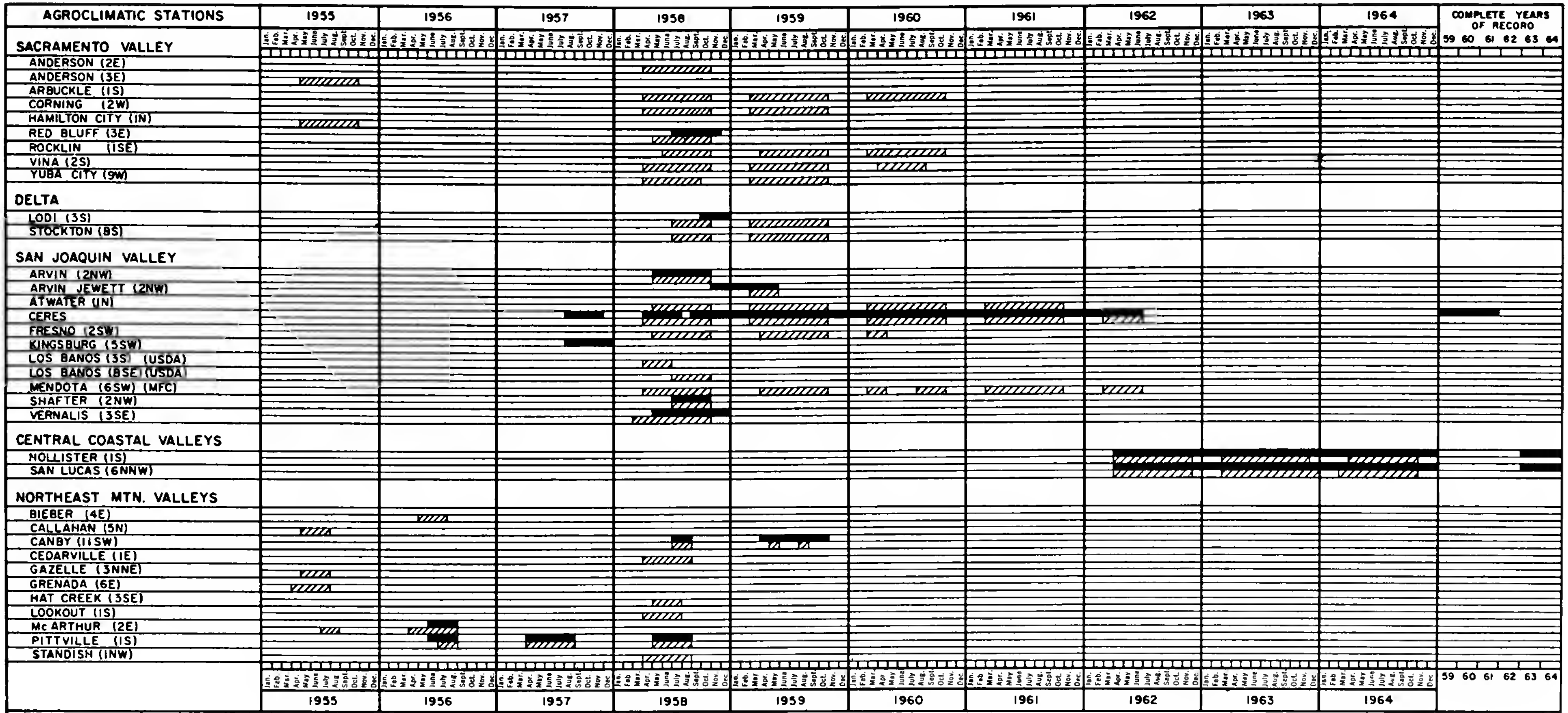
U.S. WEATHER BUREAU PAN

LIVINGSTON BLACK AND WHITE ATMOMETERS

INDICATES RECORDS THAT MAY BE USED TO EXTEND STATION DATA

INDEX TO AVAILABILITY OF HISTORIC MONTHLY EVAPORATION DATA FROM U.S. WEATHER BUREAU PANS AND LIVINGSTON ATMOMETERS LOCATED IN IRRIGATED GRASS AND PASTURE 1955-1964

FIGURE 1



NOTE: THOSE STATIONS WITHOUT NUMERICAL AND ALPHABETICAL LOCATION INDICATORS ARE LOCATED IN THE TOWN DESIGNATED. A LIST OF ABREVIATIONS ARE SHOWN BELOW.

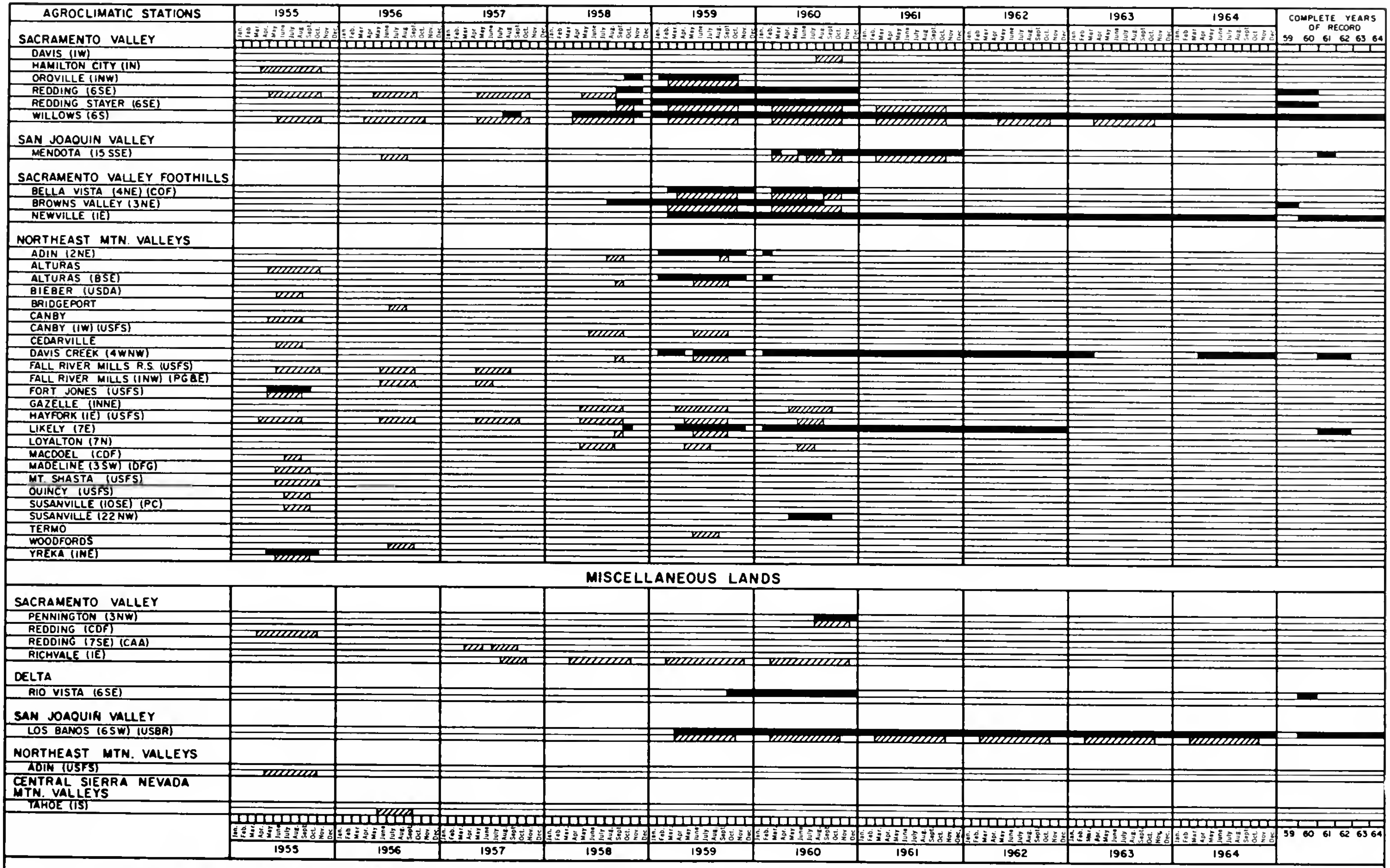
(MFC) MURIETTA FARM COMPANY
(USDA) UNITED STATES DEPARTMENT OF AGRICULTURE

LEGEND

U.S. WEATHER BUREAU PAN
LIVINGSTON BLACK AND WHITE ATMOMETERS

INDEX TO AVAILABILITY OF HISTORIC MONTHLY EVAPORATION DATA FROM U.S. WEATHER BUREAU PANS AND LIVINGSTON ATMOMETERS LOCATED IN AN IRRIGATED ALFALFA ENVIRONMENT 1955-1964

FIGURE 17



NOTE: THOSE STATIONS WITHOUT NUMERICAL AND ALPHABETICAL LOCATION INDICATORS ARE LOCATED IN THE TOWN DESIGNATED. A LIST OF ABREVIATIONS ARE SHOWN BELOW.

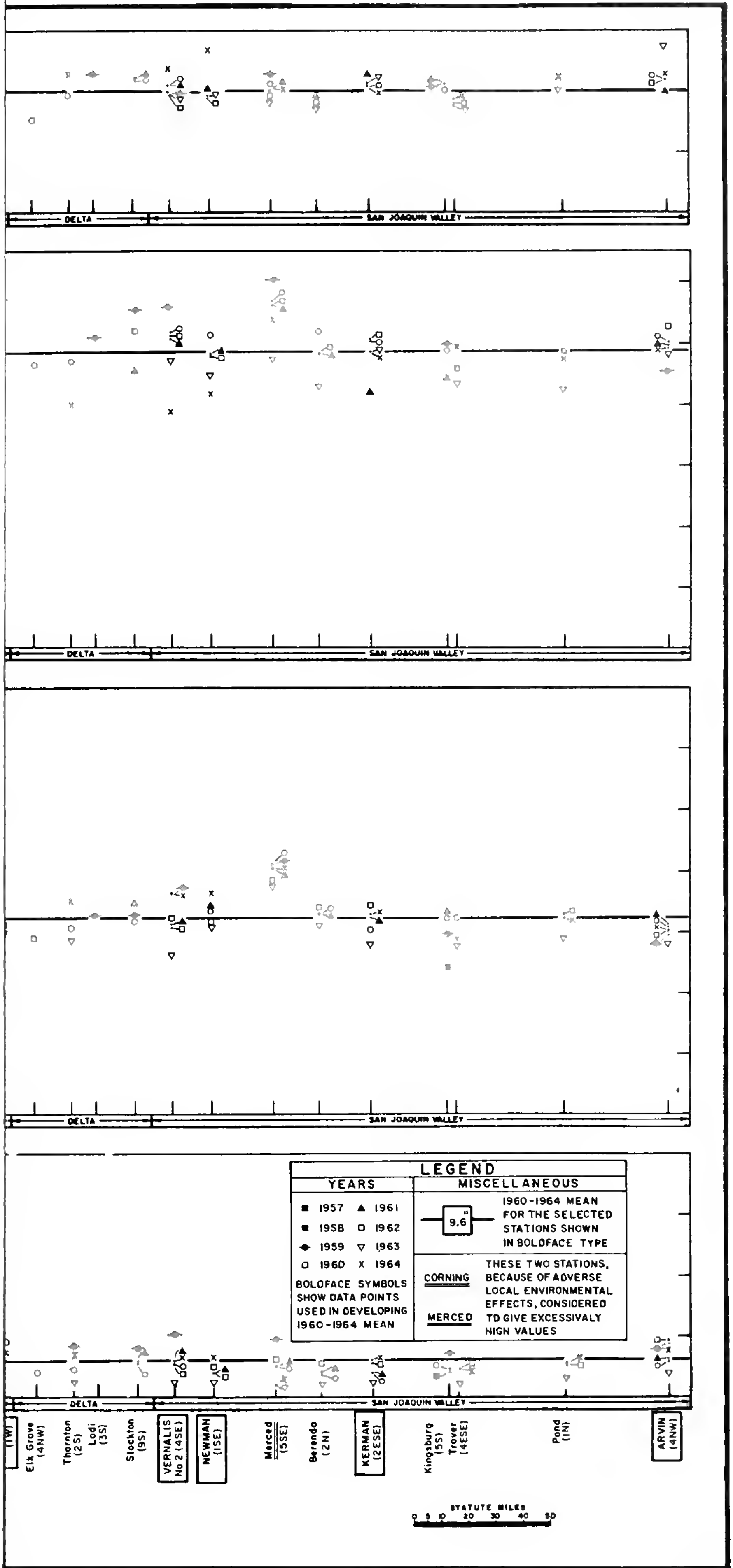
(CAA) CIVIL AERONAUTICS ADMINISTRATION
(CDF) CALIFORNIA DIVISION OF FORESTRY
(DFG) CALIFORNIA DEPARTMENT OF FISH AND GAME
(PC) PRIVATE COOPERATION
(PG&E) PACIFIC GAS AND ELECTRIC COMPANY
(USBR) UNITED STATES BUREAU OF RECLAMATION
(USDA) " " DEPARTMENT OF AGRICULTURE
(USFS) " " FORESTRY SERVICE

LEGEND

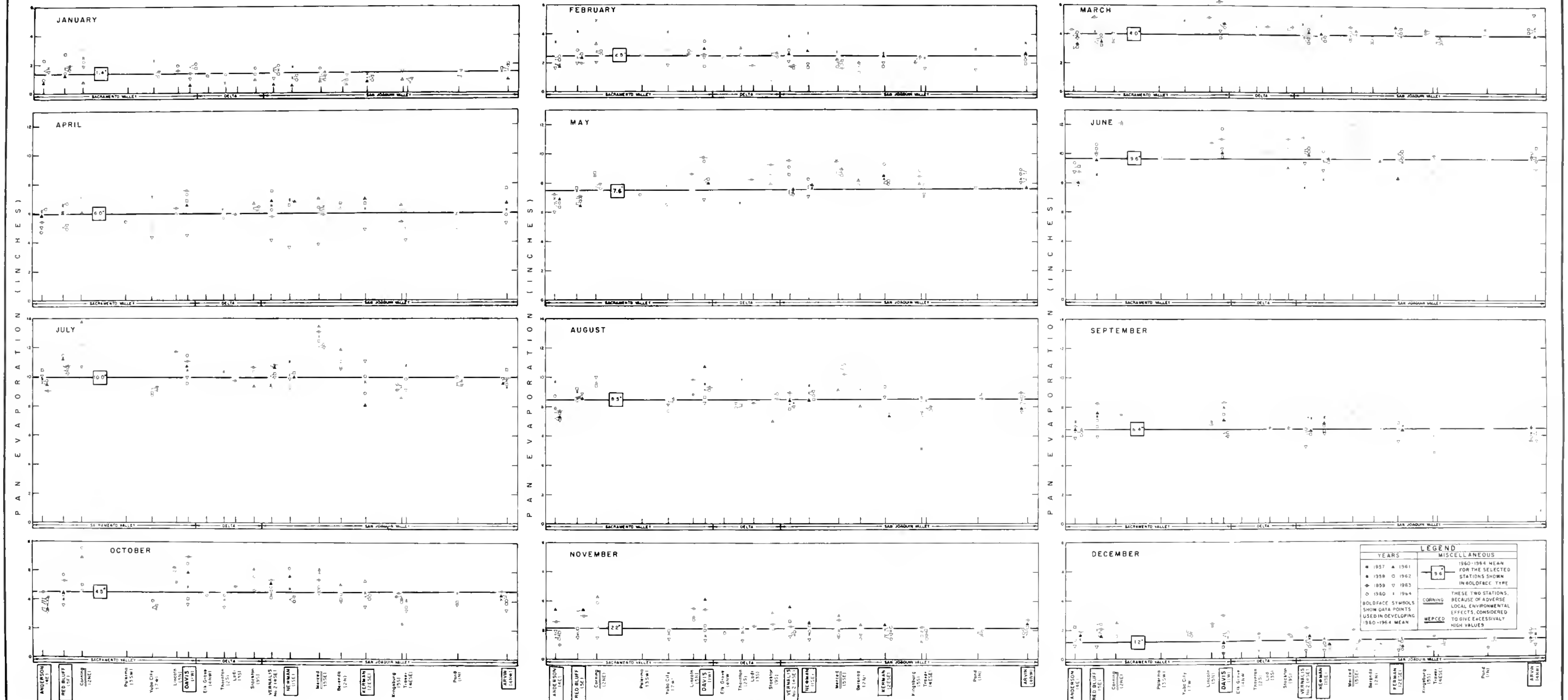
U.S. WEATHER BUREAU PAN
LIVINGSTON BLACK AND WHITE ATMOMETERS

INDEX TO AVAILABILITY OF HISTORIC MONTHLY EVAPORATION DATA FROM U.S. WEATHER BUREAU PANS AND LIVINGSTON ATMOMETERS LOCATED IN DRYLAND AND MISCELLANEOUS ENVIRONMENTS
1955-1964

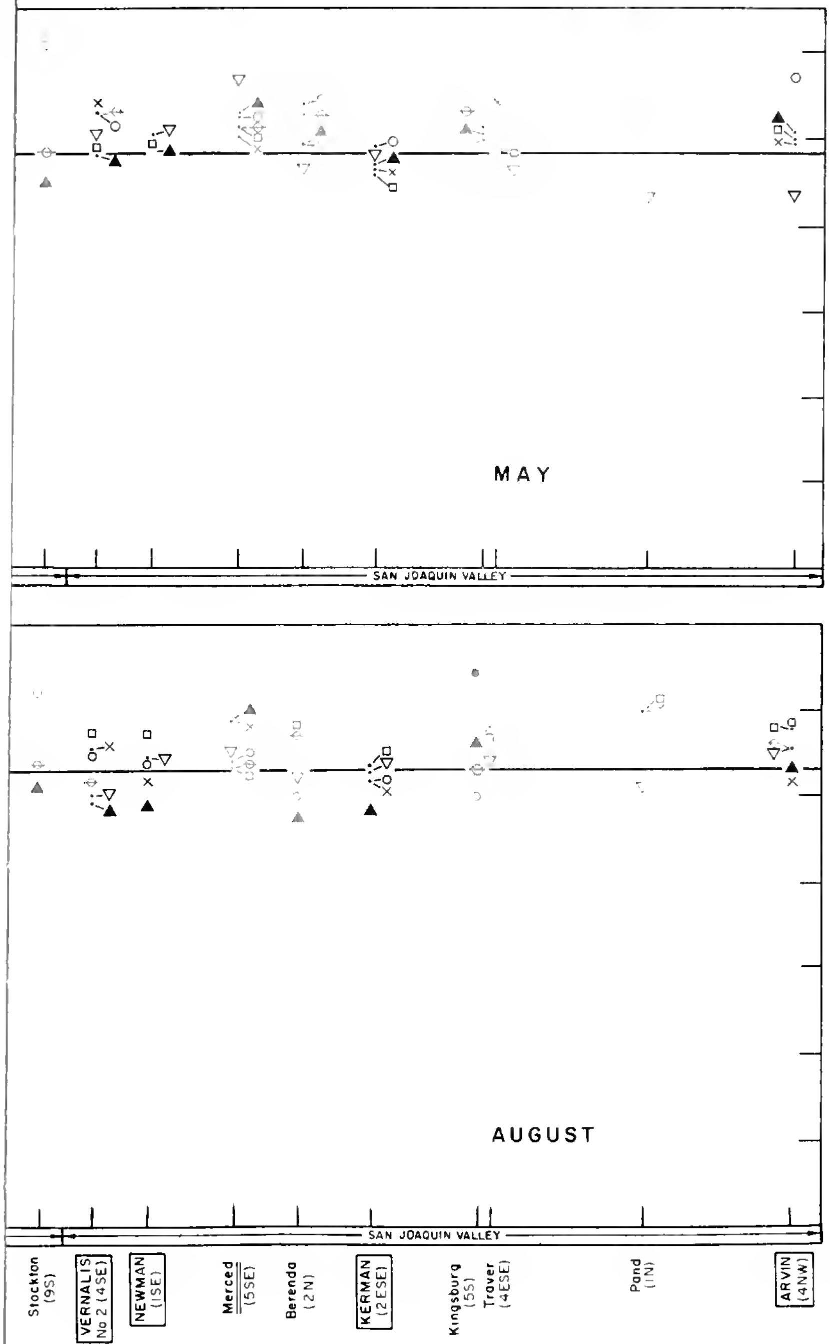
PLATE I



DELTA
SAN JOAQUIN VALLEY
LEGEND
YEARS
1957
1958
1959
1960
1961
1962
1963
1964
BOLDFACE SYMBOLS SHOW DATA POINTS USED IN DEVELOPING 1960-1964 MEAN
MISCELLANEOUS
9.6
1960-1964 MEAN FOR THE SELECTED STATIONS SHOWN IN BOLDFACE TYPE
CORNING
MERCED
THESE TWO STATIONS, BECAUSE OF ADVERSE LOCAL ENVIRONMENTAL EFFECTS, CONSIDERED TO GIVE EXCESSIVALY HIGH VALUES
(1W)
Elk Grove (4NW)
Thornton (2S)
Lodi (3S)
Stockton (9S)
VERNALIS No 2 (4SE)
NEWMAN (1SE)
Merced (5SE)
Berenda (2N)
KERMAN (2ESE)
Kingsburg (5S)
Trover (4ESE)
Pond (1N)
ARVIN (4NW)
STATUTE MILES
0 5 10 20 30 40 50



EVAPORATION TRANSECT – CENTRAL VALLEY
FROM STANDARD U.S.W.B. PANS IN IRRIGATED PASTURE

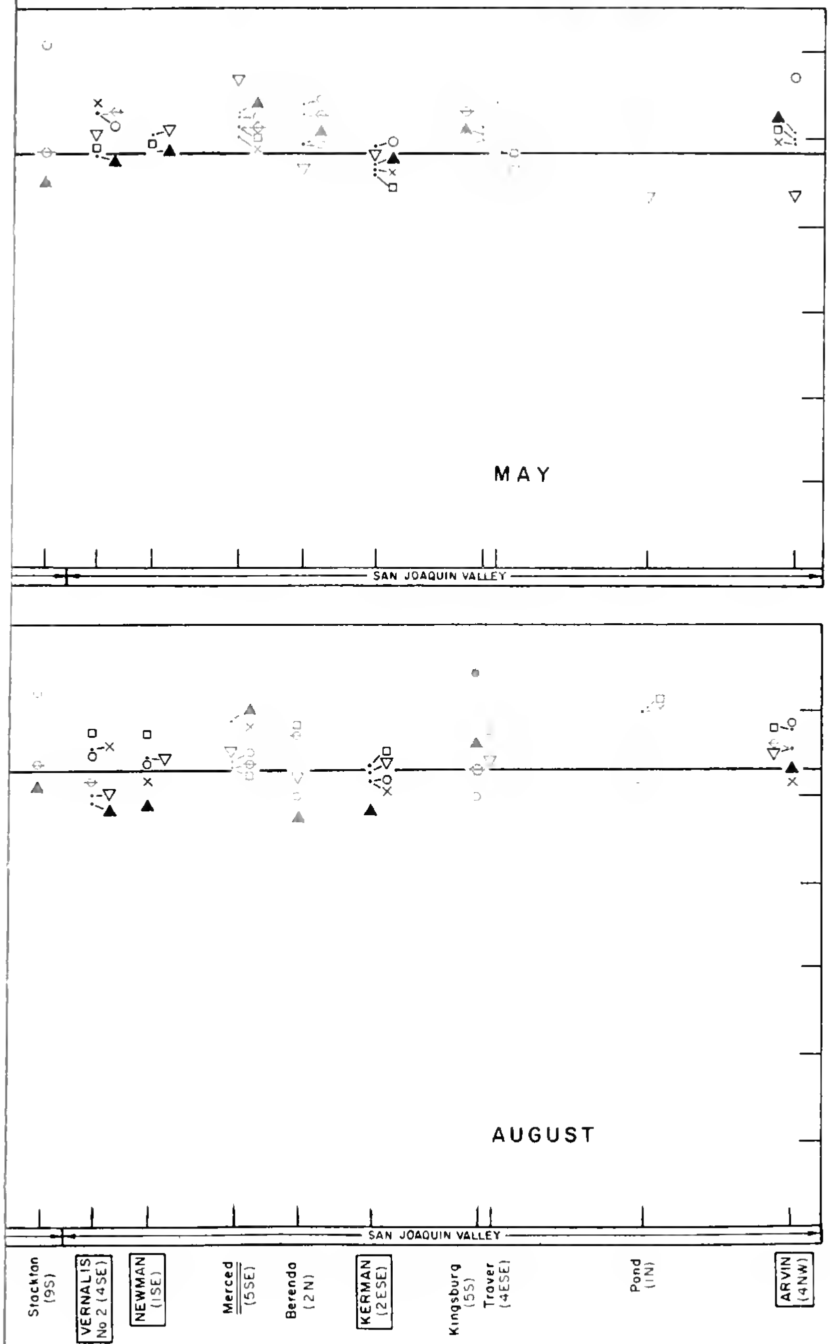


LEGEND

YEARS		MISCELLANEOUS	
■ 1957	▲ 1961	—527—	1960-1964 MEAN FOR THE SELECTED STATIONS SHOWN IN BOLOFACE TYPE
● 1958	□ 1962	CORNING / MERCED	THESE TWO STATIONS, BECAUSE OF ADVERSE LOCAL ENVIRONMENTAL EFFECTS, CONSIDERED TO GIVE EXCESSIVELY HIGH VALUES
⊖ 1959	▽ 1963		
o 1960	x 1964		

FACE SYMBOLS SHOW DATA POINTS
D IN DEVELOPING 1960-1964 MEAN)

NSECT — CENTRAL VALLEY
LACK AND WHITE ATMOMETERS
GRASS AND PASTURE

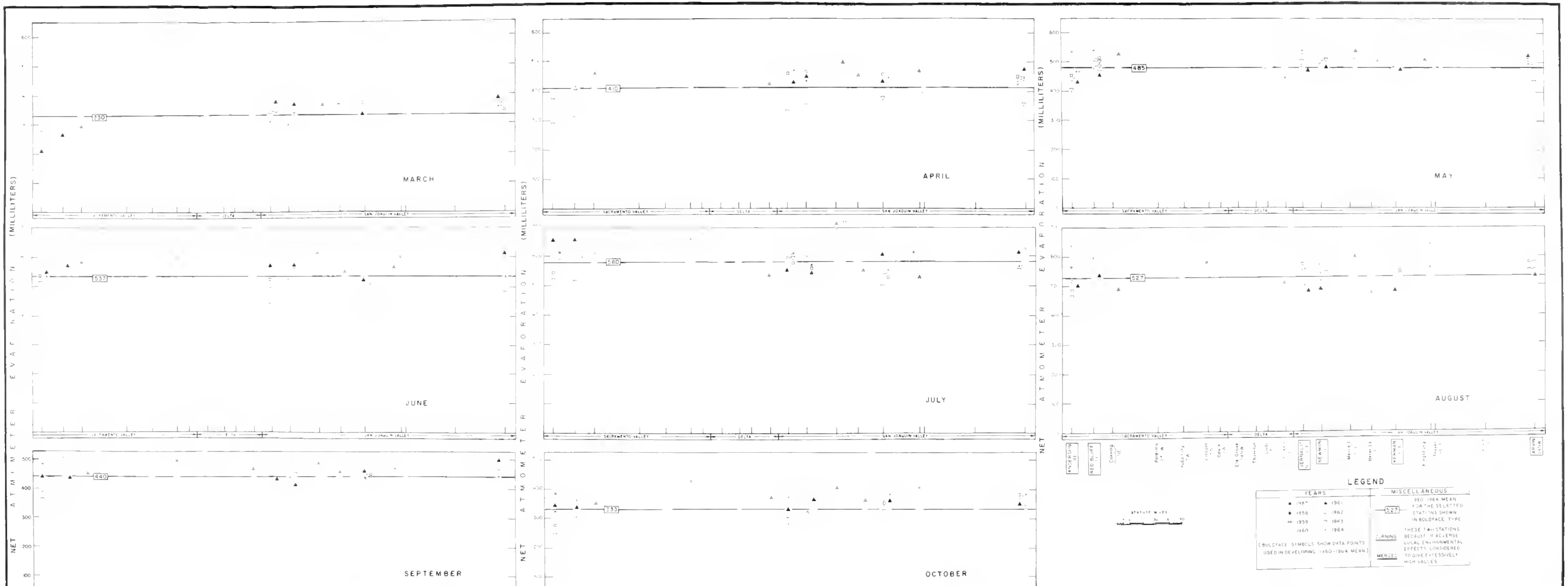


LEGEND

YEARS		MISCELLANEOUS	
■ 1957	▲ 1961	—527—	1960-1964 MEAN FOR THE SELECTED STATIONS SHOWN IN BOLOFACE TYPE
● 1958	□ 1962	CORNING / MERCEO	THESE TWO STATIONS, BECAUSE OF ADVERSE LOCAL ENVIRONMENTAL EFFECTS, CONSIDEREO TO GIVE EXCESSIVELY HIGH VALUES
⊖ 1959	▽ 1963		
○ 1960	x 1964		

FACE SYMBOLS SHOW DATA POINTS
D IN DEVELOPING 1960-1964 MEAN)

NSECT — CENTRAL VALLEY
LACK AND WHITE ATMOMETERS
GRASS AND PASTURE



EVAPORATION TRANSECT – CENTRAL VALLEY FROM LIVINGSTONE BLACK AND WHITE ATMOMETERS IN IRRIGATED GRASS AND PASTURE